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ON THE ORIGIN OF PETROLEUM.

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The question of the origin of fluid bitumens has, like many another problem of economic geology, been the subject of extensive discussion and some little controversy, even from a date prior to that which we may assign to the inception of the petroleum industry. In spite, however, of the considerable amount of thought and time spent in field, laboratory and study, the matter appears to be still *sub judice,* although it must be acknowledged that the vast majority of observers agree in attributing to petroleum in general an organic origin. The reason for this uncertainty is to a large extent the character of the minerals, which being fluid, do not like coal contain visible physical traces of their original constituents, while until comparatively recently very few indisputable instances were known of the recent formation of petroleum under circumstances similar to those which have given rise to the ancient deposits. In the third place, there was the difficulty of suggesting a feasible method by which any possible organic material could have been converted into such an homogeneous mixture of hydrocarbons as petroleum.

The difficulties referred to, with others of a minor character, drove students of the subject into two main opposing camps, viz., those supporting an inorganic, as against those who were inclined to ascribe an organic origin to bitumens. The latter theory has always claimed a larger number of adherents than the former, but

even those who were united in regarding mineral oils as of organic origin were divided on the question of whether vegetable or animal life was the main source of the material. At the present time the majority of observers who look upon oil as of organic origin also recognize that in all probability marine animals and vegetables are the chief contributors, the division being thus between those who would seek to find a source of oil in the organisms of the sea, and those who still maintain, with some of the earlier writers, that terrestrial vegetation has produced both coal and oil.

Although the inorganic theory is not the oldest in its definite form, it seems logical to deal with it first here, in view of the fact that of all those hypotheses to be discussed it is this which has now the least claim to be regarded as a possible explanation of the formation and existence of petroleum in the places where it is now found.

Prior to the formulation of the definite theory of an inorganic origin for petroleum, Brunet, in a note to the Geological Society of France,[1] suggested as a possible method of formation of asphalt, the action of nitrous and sulphurous volcanic gases on the terebenthine of conifers, which view he supported by experimental evidence. It may be mentioned that he was led to this conclusion during a study of mud-volcanoes, which he, in common with other early observers, regarded as true volcanic phenomena. Twenty years later, Rivière,[2] finding that gas leaking from the mains condensed in the surrounding soil and buried vegetation into liquid hydrocarbons, suggested that in the same way gaseous hydrocarbons of igneous origin condensed in rocks and in deposits of ancient vegetation, forming the bitumen of both. The first general theory was that advanced by Berthelot,[3] who, assuming the correctness of Daubrée's hypothesis that free alkali metals existed in the interior of the globe, suggested that infiltrating water might (as he had found in experiments) react

[1] *Bull. Soc. Geol. France*, IX., *252*, 1838.
[2] *Compt. Rend.*, XLVII., 646-648, 1858.
[3] "Sur l'Origine des Carbures et des Combustibles Minéraux," *Compt. Rend.*, LXII., 949-951, 1866.

with these to form acetylene and other hydrocarbons, the lighter unsaturated compounds being polymerized under the great pressure to form the liquid combustibles of the earth's crust. In 1871 Byasson[1] obtained in the laboratory a liquid somewhat resembling petroleum by the action on iron at high temperatures of carbon monoxide and steam, and he suggested that the same reaction might have taken place, owing to the infiltration of sea water, at great depths in the earth, with the formation of petroleum oils. Anderson,[2] objecting to the theory that oil was derived from coal, on the ground that even when oil-springs were found in proximity to such deposits there was no loss of bitumen in the coal itself, pointed to the known liability to polymerization of hydrocarbon gases, and the frequent occurrence of oil in fissures of the earth's crust, as evidence that petroleum had been formed by condensation of gaseous hydrocarbons from the interior of the earth. But the name most generally associated with the inorganic theory is that of Mendeliéeff,[3] who in 1877 published his view of the subject. Arguing from the high density of the earth and the known existence of iron carbide in meteorites together with iron in the solar system generally, he deduced the now generally accepted theory that much of the interior of the planet consists of iron, and further suggested that the metal occurs there in combination with carbon. From his laboratory experiments he was then led to suggest that the action of water on this iron carbide would have produced petroleum. But though we may attach great weight to a statement of M. Mendeliéeff's on its chemical side, it has long been recognized that the geological arguments with which he supported his theory were untenable, and that with greater knowledge of the actual conditions prevailing in the American and Russian oil-fields, from which many of these arguments were drawn, he would have found there only reasons against and none for his suggestions.

[1] "Sur l'Origine de Pétrole," *Compt. Rend.*, LXXIII., 609–611.

[2] "On the Origin of Petroleum," *Trans. Geol. Soc. Glasgow*, IV., 174–177, 1872.

[3] *Jurn. Russk. Phiz.-Khim. Obsch.*, IX. (1), 36, 37, and elsewhere.

Of later observers, Sokolov,[1] opposing the theory of the derivation of petroleum from coal or from like vegetable material, pointed to numerous occurrences of bitumen in igneous rocks, and deduced from the fact of the occurrence of carbon and hydrogen in the "pyrosphere" of the heavenly bodies, the theory that these would combine at an early stage to form hydrocarbons, which being distributed generally through the magma would thence find their way into the outer crust. Beketov[2] in 1893 carried out some more laboratory experiments which he considered as confirmatory of Mendeliéeff's hypothesis. In 1902 Sabatier and Senderens[3] produced by the action of acetylene and hydrogen on reduced nickel a mixture of liquid hydrocarbons bearing a resemblance to Pennsylvania petroleum, while acetylene alone with nickel gave a product resembling Russian petroleum.

The arguments of a geological nature advanced by the various supporters of the inorganic theory may be briefly summed up as follows:

1. The absence of an adequate quantity of organized life in many petroliferous formations.

2. The differences between the oils produced by artificial distillation of coal, etc., and the natural petroleum oils.

3. The very general distribution of petroleum in the earth's crust, regardless of the geological age of the rocks containing it.

4. The connection between igneous rocks and other manifestations of volcanic activity and petroleum.

The first of these objections to the organic theory has, it may be said, been altogether removed by further investigation, as even in the very oil-fields on the phenomena of which the argument was based evidence of abundant organic life has since been detected, and that of a character well qualified to give rise to petroleum. The second arises out of insufficient knowledge of the organic theories, for, as will be seen, so far from the supporters of these pointing to land vegetation as the sole source

[1] "Kosmischer Ursprung der Bitumina," *Bull. Soc. Imp. Nat. Mosc.*, 2, III., 720–739, 1890.

[2] *Jurn. Russk. Phiz.-Khim. Obsch.*, XXVIII. (2), 893.

[3] *Compt. Rend.*, CXXXIV., 1185–1188.

of oil, the number of authors arguing for such an origin at all is now a small fraction of the whole. It should be remembered, however, that the earlier writers on both sides often failed to distinguish adequately between carbonaceous substances exhibiting traces of vegetable structure, such as coal and lignite, and those which are now, by general consent, considered as derivatives or allies of petroleum.

Though petroleum does occur in greater or less quantity in rocks of all geological ages, it may be said that its quantity is far greater in rocks deposited under such conditions as would ensure the entombment of large quantities of organic material, and where the conditions of a particular period were throughout the world unfavorable to the formation of petroleum, that division of the geological record is nearly or entirely barren of the mineral.

Finally, it is now known that the mud-volcanoes so frequently accompanying petroleum are not of igneous origin, and that in fact true volcanic energy is seldom, if ever, manifested in petroliferous regions, while the number of occurrences of petroleum in igneous rocks bears only a small proportion to the number of such occurrences in sedimentary deposits far from any known mass or outcrop of igneous rock.

Against the theory as a whole may be urged the difficulty of understanding how the petroleum of such deposits as those of Pennsylvania and Baku (in fact the majority of geologically-known oil-fields of the world) could have reached its present position if derived in any way from the central magma of the earth, while it is also difficult to reconcile with the inorganic theory the fact of the extreme rarity of petroleum in the oldest solid rocks of the earth's crust and in any such igneous masses as are precluded by their mode of occurrence from containing oil derived from surrounding sedimentaries. It may be added that, as emphasized by Phillips,[1] natural gas contains only a small proportion of hydrogen, whereas the synthesized gases of the igneous theorists contain very large proportions of that element, and no adequate hypothesis has yet been advanced to account for its elimination.

[1] *Amer. Chem. Journ.*, XVI., 418, 1894.

But recent investigations on the optical activity of petroleum and its cause have practically placed the organic origin of petroleum in general beyond dispute. These investigations will be more fully discussed later, but it may be said here that these optical phenomena are not manifested in inorganically synthesized petroleum,[1] and that the substances to which this activity is believed to be due can only be derived from organic matter.

Among the numerous instances of the occurrence of traces of petroleum or gaseous hydrocarbons in igneous rocks, there may be some[2] which are indigenous and formed in the manner suggested by the chemists already referred to, for the elucidation of which question it is now possible to test the oil for optical activity, and for cholesterol or phytosterol (the substances above referred to); should these not be found, then the possibility of an igneous origin may be admitted for these occurrences, which are in general of purely academic interest, while leaving the difficulties still equally insurmountable for those who would attribute an inorganic origin to petroleum generally.

The authors whose views have been discussed above, since they derived in theory their materials as elements from the original magma of the earth, were concerned chiefly with the methods by which these elements were to be brought together, but on the organic side, together with the determination of the particular form of living matter, must be considered the method by which the carbon and hydrogen of these bodies, frequently forming part of complex molecules, are to be rearranged into the comparatively simple compounds forming the greater part of the familiar mineral oils.

It has already been pointed out that the division of opinion to-day among the supporters of an organic origin lies mainly between those who consider coal and oil alike derived from ter-

[1] Rakusin, *Jurn. Russk. Phiz.-Khim. Obsch.*, XXXVIII. (1), 1129–1135, 1906.

[2] Such instances as the asphalt veins of the basal granite of Auvergne which are clearly derived from the overlying petroliferous Miocene deposits, suggest that even the most problematical deposits of this kind may have had a similar origin from sedimentary rocks, but this can hardly be applied to the meteoritic hydrocarbons, see Smith, *Amer. Journ.*, 3, XI., 388–395, 433–442, 1876; and Meunier, *Compt. Rend.*, CIX., 976, 977, 1889; etc.

restrial vegetation, and those who consider that other organisms form the main part of the original material of petroleum.

The question of the part played by the remains of highly organized animals needs no extensive discussion, owing to the very general absence of large quantities of such fossils in the ordinary sedimentary rocks. The point will, however, be considered in its place.

Prior to the discussion of the origin of petroleum as a substance deserving separate study, numerous general treatises included it with coals, resins, etc., as derived from fossil land vegetation by distillation. The majority of superficial observers were thus led to regard all inflammable mineral substances as of one origin. But later writers have also considered that terrestrial vegetation has in some cases undergone a special mineralization, being changed to liquid and gaseous hydrocarbons in place of the usual solid lignites and coals. In 1860, Wall, finding oil in Trinidad and Venezuela in a series of limestones, sandstones and shales, associated with beds of lignite, was led to suggest that the latter had given rise to the oil,[1] but in the same year Deleasse[2] had found .256 per cent. of nitrogen in Trinidad pitch, which, though no clear proof of its animal origin, was evidence in its favor, and was explicable in the light of Prof. Rupert Jones's discovery that the matrix of his samples of the asphalt was composed of Nummulinæ and *Orbitoides*.[3] In 1897 Peckham studied the occurrence of plant remains associated with asphalt in Trinidad, on the basis of which Wall had built up his theory, and found that the lignite bed near the lake, and the pieces of lignite in the asphalt itself, were in exactly the same condition, that is, they were both still wood, and that the bitumen could certainly not have come from these, in his view.[4] Griffiths, in 1884, finding free phenol in pine cones, again suggested that petroleum was derived from the decomposition of conifers, on the ground of the occurrence in some mineral oils of a small proportion of the same

[1] *Quart. Journ. Geol. Soc.*, XVI., 467.
[2] *Ann. Mines*, 5, XVIII., 151, 1860.
[3] *Quart. Journ. Geol. Soc.*, XXII., 592, 593, 1866.
[4] *Proc. Amer. Phil. Soc.*, XXXVI., 105, 1897.

compound.[1] Sadtler also suggested the participation of land vegetation in the formation of petroleum, on the ground that vegetable fats such as linseed oil could be made to yield both kerosene and solid paraffin like those obtained from natural petroleum.[2]

As early as 1869 it was clear that the supporters of the land vegetation theory were faced with a problem of considerable difficulty in accounting for the very general lack of association of deposits of coal or lignite and oil.[3] It is now, with increasing knowledge of the geology of oilfields, more than ever difficult to reconcile the facts of the occurrence of petroleum with the theory of its derivation from land vegetation, both on account of the general absence from oilfields of remains of such organisms (at least, in any quantity), and also because where, as occasionally happens, lignite or carbonized fossil wood occurs in association with petroleum deposits, the substance is of the usual character and has lost none of its essential components. Lesquereux's researches on the occurrence of fucoids in coal measures[4] have, indeed, made it questionable whether a good deal of the bitumen content of the solid combustible minerals may not be derived from marine life.

Sokolov,[5] who does not appear to have studied the organic theory fully, objected to it on the ground that while coals contain less than 5 per cent. hydrogen, bitumens always contain nearly twice as much. But the strongest evidence on the chemical side is obtained from a study of the tars distilled from wood or lignite, from which paraffin and other mineral oil products are obtained.[6] These tars include large quantities of such compounds as benzene, phenol, oxyphenol $C_6H_6O_2$, sylvane C_5H_6O, kreasol, naphthalene and other aromatic hydrocarbons, and exhibit in every way considerable differences from petroleum, while it may be

[1] *Chem. News*, XLIX., 95.

[2] *Amer. Journ. Pharm.*, LXVIII., 465–467, 1896.

[3] See Credner, "Ueber die Entstehung des Erdöls," *Zeitschr. ges. Nat.*, XXXIII., 304, 1869.

[4] *Trans. Amer. Phil. Soc.*, XIII., 313, 1866.

[5] 1890, *loc. cit.*

[6] See Redwood, "Petroleum and its Products," Ed. II., pp. 461–474, 1906, and Mills, "Destructive Distillation," Ed. IV., p. 88, 1892.

added that the compounds more characteristic of rock oil do not appear in the original distillation until a high temperature has been reached, and there is no evidence in most petroleum deposits of such a temperature having been experienced.

The author has already referred in a previous paper[1] to the possibility of lignite having been partly bituminized in Galicia, Trinidad and Assam, where fossil wood has been found associated with petroleum, but with abundant marine life at hand to account for the existence of the oil, it cannot be regarded as in any way proven that in any of the cases mentioned lignites have been thus transformed into fluid bitumens. At the same time, the experiments of Prof. Sadtler on linseed oil suggest that the parts of land-plants which are particularly rich in fats may have contributed in some small degree to the production of petroleum: that this has been so in some cases is suggested by the researches of Herr Potonié,[2] who finds in mud from the Gulf of Stettin, together with marine plant and animal remains, a considerable quantity of the pollen of land plants; this mixture yielding on distillation oil like petroleum. These researches will be discussed later, but the possibility of the contribution of land vegetation to petroleum in this way admits such organisms in a very limited sense as origin-material.

To sum up the arguments against the theory of the derivation from land-plants of petroleum either wholly or generally, there is the absence of connection between carboniferous and petroliferous strata, nowhere better exemplified than in the Appalachian region, where the coal-productive measures are barren of oil and vice-versa; there is the evidence of the limestone oils which cannot have been derived from land vegetation; there is the perfectly normal character of lignites or coals found near or in association with oil springs or petroleum deposits; and finally, the great chemical difference between lignite tar oils and natural petroleum, with the high temperatures, necessary from a chemical point of

[1] This Journal, IV., 110, 1909.

[2] "Zur Frage nach den Ur-Materialen der Petrolea," *Jahrb. k. Preuss. geol. Landesanst.*, XXV., 342–368, 1904.

view but impossible[1] from a geological standpoint, required to convert wood into liquid bitumen without leaving a trace of the original structure. These objections have never been satisfactorily met, and we may therefore prefer a theory presenting fewer difficulties, if such can be found.

Before passing to the last and most generally accepted theory, we may again notice the part possibly played by the remains of highly organized animals, a view of the subject not widely dealt with, for the obvious reason that mammalian or saurian remains are comparatively rare in the geological record, and particularly so in the classical oil-fields of the world. But it is conceivable that where the bodies of such have been buried in sediment, the fats, which are known to persist as adipocere (under the influence of damp soil etc.) after the total decomposition of the nitrogenous portions of the body, may have in some cases been changed into petroleum. That the suggestion may apply to a considerable extent to certain oils is hinted by Peckham, who[2] pointed out that Dippel, ca. 1760, produced pyridin by the destructive distillation of the bone and tissue of highly organized animals, and that this substance had never been found in nature until it was recognized in bitumen from Ventura County, California, which occurs in strata full of the remains of Miocene marine mammalia. It cannot but be recognized that this is of little weight as a general theory of the origin of petroleum, for the geological reasons already referred to. No better introduction to a study of the modern theory of the dual origin of petroleum could be given than Dr. Engler's words in his report on the distillation of the marine organic mud, contained in Herr Potonié's paper already quoted, where, in commenting on the evidence there adduced that marine plant and animal remains may be converted into petroleum, he says:[3]

[1] An exception must of course be made in cases where intrusive igneous rocks have passed through strata containing terrestrial vegetation, instances of the local occurrence of oil so formed being furnished in the Lothians of Scotland, the Karroo regions of South Africa, and in the Mendoza district of the Argentine Republic.

[2] *Amer. Journ.*, 3, XLVIII., 394, 1894.

[3] *Loc. cit.*, p. 350.

I myself admitted the possibility of the formation of petroleum from marine organisms of this kind, as soon as I obtained knowledge of such; but never in the sense of the old vegetable theory that wood, etc., may be transformed into petroleum, only in the sense of my view, which is supported by experiments, that it is formed from the fatty remains of marine organisms. The determination of the kinds of such organisms seems to me to be the business of geologists, or better of biologists and palæontologists.

This point of view is further discussed in his excellent lecture on the origin of petroleum, delivered at Jena in May of last year.[1]

The probability of the dual origin of petroleum has, however, not always been so fully recognized as at present, many writers having investigated the claims of animal organisms only, while a few have laid undue stress on the part played by marine vegetation.

One of the first to suggest an animal origin for petroleum was Leopold von Buch, who in 1803 considered that the bitumen of the Württemberg Liassic shales was derived from the animal remains contained therein. Sir Roderick Murchison in 1829,[2] in an account of the bituminous shale of Seefeld in the Tyrol with its abundant fossils, remarked on "the probability of so many fish having materially coöperated in the bituminization of the schist, because this rock, on distillation, gives off a much larger proportion of ammonia than has ever been detected in any coal however bituminous." In 1865, Warren and Storer[3] published an account of the hydrocarbons derived from the distillation of the lime-soaps of Menhaden fish-oil, which experiments may be regarded as the forerunners of the better known researches of Dr. Engler to be referred to shortly. Rofe[4] in 1866, emphasing the great difference between common and cannel-coal, suggested that the abundant fish remains of the latter contributed to the difference in bitumen content, and further alluded to the possible part played by sea-weed in the formation of cannel, a view which has been shown correct by the later researches of Bertrand and Renault. The

[1] *Zeitschr. angew. Chem.*, XXI., 1585–1597, 1908.
[2] *Proc. Geol. Soc.*, I., 139, 146.
Mem. Amer. Acad., 2, IX., 177–207.
[4] "Note on Coal and Cannel," *Geol. Mag.*, III., 208, 209.

evidence brought forward by Prof. Rupert Jones as to the possible animal origin of Trinidad petroleum has already been referred to. Fraas,[1] in 1868, attributing an animal origin to petroleum, referred to the presence in Egyptian fossil Carditæ, Naticæ, etc., of black asphalt, and to the oil of the coral reefs of the Red Sea. Knab[2] strongly advocated an animal origin for the Val de Travers asphalt and other bitumens, using as arguments the quantity of ammonia present and the existence of fossil oyster banks with the known rate of reproduction of those animals. Kreutz,[3] in 1881, adduced the abundant fish, bryozoa and foraminifera of the petroliferous Ropianka beds of Galicia, as evidence of the animal origin of that oil. But in 1888, the striking experimental data published by Engler,[4] with the discussion of the question by Höfer,[5] did much to strengthen the theory and to place it upon a scientific basis. Dr. Engler's experiments consisted in the distillation of fish oil, from which a petroleum-like liquid was obtained. He used a Krey's apparatus and carried out the experiments at Webau. For the trial, 492 kilos. of north American fish oil, from the menhaden fish, of sp. gr. .930 (20° B.), was employed and this was heated to a temperature of 320°–400° C., the initial pressure being 10 atmospheres, afterwards reduced to 4 atmospheres. The quantity of distillate obtained was 217 kgs., which was of a brownish color, with green fluorescence and odor of acroleïn. Its specific gravity was .8105 (43° B.). This crude distillate was fractionated, and thereupon yielded the following parts:

	Under 150°.	150° to 300°.	Over 300°.
By volume.....	29.5 per cent.	57.5 per cent.	13 per cent.
By weight.....	25.9 per cent.	58 per cent.	16.1 per cent.
Sp. gr.....	.712 (67.3° B.)	.817 (41.7° B.)	

These fractions were then treated with concentrated H_2SO_4 and afterwards with soda lye and water, the refined burning oil so obtained being described as indistinguishable from commercial kerosene.

[1] *Bull. Soc. Sci. Nat. Neuchâtel,* VIII., 58–61.
[2] *Ibid.,* 226–238.
[3] *Verh. k.k. geol. Reichs.,* pp. 28, etc.
[4] *Ber deutsch. chem. Ges.,* XXI., 1816–1827, 1888; XXII., 592–597, 1889.
[5] *Das Erdöl.*

Triolein and tristearin were distilled and yielded similar results, and these facts, with the occurrence of nitrogen in Trinidad pitch and in many of the American oils, as well as in Alsatian, Chinese and Galician petroleums, and the discovery of crystals of ammonium carbonate in natural gas wells at Pittsburg, led Dr. Engler to propound his theory of the animal origin of petroleum.

He endeavored later to obtain petroleum from the distillation of fish and mollusca, but found that this gave a very large quantity of ammonia and other nitrogenous bases; he therefore inferred that in the formation of petroleum the process of decomposition often observed in buried organic matter always takes place, namely, the nitrogenous parts and all material except the fats are removed, while these last by a slow process of natural distillation in the earth give rise to petroleum.

In 1892, Jahn[1] described the occurrence in dolomitic Silurian limestone of Orthoceratites and lamellibranchs full of petroleum, which, he suggested, was further evidence in favor of animal origin. In the same year, Bertels advanced the opinion that the Caucasian oil was produced by the decomposition of molluscs. Kharitchkov[2] investigated the nitrogen content of Russian oils, and adduced his results as evidence in favor of an animal origin, while Neuburger,[3] in 1901, attributed Algerian and other oils to this source on similar grounds.

Lastly, Morgan and Tallmon[4] finding bitumen in a fossil egg, proved fairly conclusively that it had originated from the contents and thus added to the evidence supporting the possibility of the transformation of animal matter into petroleum in nature without the exercise of any undue heat or pressure.

In support of the theory that marine vegetation has been a large, and perhaps in some cases the sole contributor to the origin-material of petroleum, a considerable amount of evidence has been adduced, though it cannot be said that this side of the question has appealed to so many minds as that just discussed.

[1] *Jahrb. k.k. geol. Reichs.*, XLII., 361–376.
[2] *Gorn. Jurn.*, 1898, I., 356–358.
[3] *Rev. Sci.*, XVI., 48–52.
[4] *Amer. Journ.*, 4, XVIII., 363–377, 1904.

In 1866, Lesquereux[1] drew attention to the arguments in favor of the vegetable origin of the Pennsylvania oils, and referred to the recent formation of a liquid akin to petroleum in Sardinia and Sweden. In the former the salt-marshes are frequently covered with masses of sea-weed, and these can be observed decomposing into petroleum-like oil, in Sweden, on the shores of The Sound, in the neighborhood of Lund, sea-weed buried in the shore sand has been found to decompose into a similar substance. He referred to the abundant remains of fucoids in the Devonian shales, and generally in association with the Pennsylvania oil deposits, as presumptive evidence that this petroleum had been formed in the same way. He further suggested that the green color of the Devonian oil, being exactly like that of the Chlorosperm Hydrophytes, was due to the persistence of the coloring matter of these plants. In 1882, Newberry[2] supported the same view, pointing out that beneath the Pennsylvania oil-sands there was 500 feet of bituminous shales with abundant fucoid impressions, while the Collingwood shales of Canada occupied a similar position relative to the northern deposits. He also showed how the cellular tissue of sea-weeds would be easily disintegrated; finally, it may be noted that he included Radiolaria, Graptolites and other low forms of animal life in his origin-material. The bituminous matter of cannel coal or boghead came, he suggested, from microscopic water-plants. The researches of Bertrand and Renault[3] are of great interest in this connection, as these writers were able to trace the origin of the boghead of Autun and of the kerosene shale of New South Wales to algæ, though these peculiar bitumens also contain animal remains. They named the chief alga of the Autun deposit *Pila Bibractensis* while that from the kerosene shale was *Reinschia australis*. Renault[4] finds Pila scotica and *Thylax britannicus* in Scotch oil-shale. Phillips,[5] in 1894, carried out some experiments relating

[1] *Bull. Soc. Sci. Nat. Neufchâtel*, VII., 234–238; and *loc. cit.*

[2] *Ann. New York Acad. Sci.*, II., 267–286, 357–367.

[3] *Bull. Soc. Linn. Normand.*, 4, VIII., 323, 324, 1894; *Compt. Rend. Assoc. Franc.*, 1893, II., 490, etc.

[4] *Bull. Soc. Ind. Min.*, 3, XIII., 1022, 1899.

[5] *Loc. cit.*, p. 427.

to the origin of natural gas, and found that the products of decomposition of sea-weed under ordinary conditions were methane CH_4, hydrogen, nitrogen and CO_2 which he considered as evidence in favor of the vegetable origin of Pennsylvania natural gas, since that made from Engler's menhaden distillate contained ethylene and CO, neither of which compounds occur in the gas of the Appalachian field. He also pointed out that while vegetable tissue at first decays rapidly it afterwards decomposes slowly, while the rate for animal matter was rapid and constant. In 1897[1] he also argued against the animal origin of oil because he found that in fossil coral reefs in the limestone of Niagara County, N. Y., while some of the cells contained petroleum, others did not, and he thought that it might therefore be supposed that the oil was not derived from the coral itself; moreover, in spite of the finding, by Fraas, of oil in the coral reefs of the Red Sea, none was formed in those of Bermuda and Florida. The first argument is hardly conclusive, while in regard to the second it might be urged that the conditions in Bermuda and Florida are not normally such as to allow any oil formed to collect in appreciable quantity, as it can, and does, in the Red Sea. Apart from this, however, his experiments are interesting as being the earliest laboratory evidence for a marine vegetable origin. Also in 1894, Dr. O. N. Witt, in a short article on the origin of petroleum[2] suggested that microscopic water plants might have contributed to mineral oils even more largely than more highly organized vegetation, and this view has lately been taken up and studied by Krämer and Spilker.[3] They found that when the mud of Stettin Gulf near Ludwigshof was lixiviated with benzene, and the solution evaporated, a yellow to dark brown, paraffin-like substance was left, hardly attacked by Nordhausen acid in the cold. It was fusible, and could be made to crystallize from alcoholic solution. Its melting point was 75° C., and in many ways it bore a great resemblance to ozokerite. On ignition it left .242 per cent. ash, and was also found on analysis to contain a considerable percent-

[1] *Proc. Amer. Phil. Soc.*, XXXVI., 121–126.
[2] *Prometheus*, V., 349, 350, 365, 366.
[3] *Ber. deutsch. chem. Ges.*, XXXII., 2,940, 1900; XXXV., 1212, 1902.

age of oxygen. This wax on distillation gave products like petroleum, and they compared with these the liquids obtained by the distillation of ozokerite, which were similar. They considered that the salt associated with ozokerite was adequate proof of the marine origin of that mineral. A further examination of the mud showed that it gave about 3 per cent. by weight of wax, a quantity sufficient to produce a large quantity of petroleum in relation to the bulk of the deposit, and they in this way establish the claim of the wax of diatoms to be considered as a possible source of petroleum, remarking on the fact that the majority of observers had ignored "die enorme Bedeutung der wachserzeugenden Tätigkeit der niederen Pflanzenwelt." Opinions are divided as to whether ozokerite is a direct product of the decomposition of organic matter or of the natural desiccation and oxidation of liquid petroleum, but the researches at least point to the fact that natural decomposition of plant remains, especially of the lower forms, may give rise to petroleum-like substances.

The examination of two quasi-mineral deposits, namely, the "coörongite" of South Australia, and the "n'hangellite" of Portuguese East Africa, has given some interesting results relative to the connection between algæ and petroleum. Both of these substances were mistaken for elaterite or elastic bitumen, and as both yielded oils like petroleum on destructive distillation, syndicates were led to prospect for oil (without success) near the deposits. The African material has been examined recently and Mr. Boodle, of the Royal Botanic Gardens, Kew, says:[1] "From such details as could be determined there seems to be no doubt that the matrix has been derived from a gelatinous organism belonging almost certainly to the blue-green algæ, among which it would be classed under the Chroococcaceæ." The substance includes also diatoms, sponge spicules, etc. Sir Boverton Redwood, from whom the author received a sample of the material, analyzed it[2] with the following results from the substance freed from ash:

[1] *Bull. R. Bot. Gardens, Kew*, 1907, 146.
[2] *Ibid.*, pp. 151–153.

Carbon	69.63 per cent.
Hydrogen	10.35 per cent.
Nitrogen	2.50 per cent.
Oxygen (by diff.)	17.52 per cent.

By destructive distillation it gave on an average 49.6 per cent. of oil, 9.3 per cent. of water, 19.7 per cent. of gas and 21.4 per cent. of coke, the oil being much like petroleum and containing 3.8 per cent. of paraffin. It would seem that this substance is therefore a mass of algæ, which, being dried up under a tropical sun on the sandy plains near Inhambane, has, as it were, reached an intermediate stage in the production of petroleum from aquatic vegetation.

The evidence above quoted in support of the theory of the derivation of petroleum from marine organisms seems in the aggregate to have fairly established the possibility of the participation of both animal and vegetable matter in the process, but it should be recognized that on both sides the final outcome of the study of the various writers is to limit the direct origin-material to the fatty matters of the bodies concerned, the nitrogenous tissues being eliminated first.

There are two difficulties which have to be considered in placing the dual theory on a sound basis, namely, the manner of accumulation of the amount of organic material necessary to produce the oil of the ordinary petroliferous deposits, and the methods by which this may have been changed into petroleum.

For the first question the only adequate solution would perhaps be an extension of the experiments of Krämer and Spilker, etc., to the sediments now being laid down in different parts of the world, an investigation which would probably give results of great value, in showing, not only the amount of the organic content of such deposits, but also the conditions under which this content reaches its maximum. The researches of the chemists named have shown that the mud of one locality at least contains a large enough percentage of organic matter to form a considerable amount of bitumen, while other data are forthcoming to suggest that similar results might be obtained elsewhere.

In 1898 some interesting evidence on the point was furnished

by the investigations of the Austro-Hungarian Deep Sea Expedition. Natterer describes the occurrence of petroleum in the mud of the Mediterranean sea-floor between Cyprus and Syria, and in the sea-water immediately above the bottom; it was also found in the Gulf of Suez, and in each case ammonia and iron sulphide or sulphur occur with the oil. In reference to the formation of oil in the Mediterranean, he says:[1] "On the submarine slopes of the coast of Palestine and Syria the remains of small plants and animals fall to the bottom in considerable quantities, being carried thither by the great masses of water which sweep in throughout the whole depth of the sea from the west, and curve round to the north." These facts suggest that where any evidence is forthcoming as to the direction of the currents prevalent in ancient areas of deposition, it may aid in determining the part of the basin likely to be richest in petroleum, if the sediments have there been thrown into such form as to ensure the local concentration and preservation of the oil contained therein. The tendency to concentrate along anticlinal folds will doubtless in time largely efface the effect of any such local intensity of petroleum-forming conditions, but the latter may be a reason for the occasional apparently erratic differences between the productivity of the various fields of a given area. But the present value of the "Pola" observations lies in the fact that they show that at least in the Levant and the Red Sea so much organic matter is being buried in the sediments that the petroleum formed by its decay not only impregnates these rocks of the future, but is distributed through the lowest strata of the sea itself, sulphur or sulphides being also formed in the process. Potonié's study of the Ludwigshof mud has already been referred to, and Engler obtained by destructive distillation of this mud a petroleum-like oil containing crystallizable paraffin.[2] This mud contained diatoms and other organic remains, and some from the Neuwarp "Lake," a bay of Stettin Gulf, contained the following:[3]

[1] *Scott. Geogr. Mag.*, XIV., 639, 1898; see also "Chemische-geologische Arbeiten der 'Pola' Expedition," *Verh. siebent. internat. geogr. Kongr.*, II., 326–333, 1901.

[2] *Jahrb. k. preuss. geol. Landesanst.*, XXV., 347, 1904.

[3] *Jahrb. k. preuss. geol. Landesanst.*, XXIV., 404–409, 1904.

Sponge spicules (few).
Crustacean remains (abundant).
Fish remains (few).
Much amorphous material—excrement of animals and similar substances from plants.
A small quantity of calcareous matter, phytogenous and zoögenous.
Very many algæ and diatoms.
Pollen of land and water plants.

To this organic mud or "Faulschlamm" he gave the international cognomen of "Sapropel," and he traces the various stages in the formation of bituminous matter, etc., from sapropel.[1]

In an interesting paper on the geographical rôle played by algal growth, Dr. Fritsch[2] describes the abundant vegetation of this kind in a salt marsh in the Bouche d'Erquy, Brittany. The whole paper is instructive as showing the rapid increase of these plants under favorable conditions, and in the instance referred to is interesting as offering a suggestion relevant, in the present writer's view, to the subject under discussion.

> According to the level they occupy, these pans are more or less frequently overrun by the tides, and their water is consequently brackish. They harbor a rich growth of *Rhizoclonium* and *Lyngbya,* often intermingled with abundant colonies of *Chroococcus,* etc., and diatoms; . . . The algal growth is often very thick . . . almost every tide will probably deposit a small amount of mud and sand on the surface of the alga, and the latter will thus gradually become embedded. The buried portion will form humus by decay, whilst fresh branches from the alga will continue the growth on the surface. The soil thus formed constitutes a black evil-smelling sandy mud, owing to the decomposing algal substance. Borings have shown that strata of a similar black sandy character are present at varying depths below the present level. . . .

It is not intended to suggest that petroleum deposits have been formed actually in this way, but one has only to observe the abundant algal growth of the sea bottom, as may be done in the clear waters round the Ionian Islands, to understand how an analogous

[1] Greek: σαπρός = putrid, πηλός = mud.
[2] *Geogr. Journ.,* XXX., 544, 1907.

process may be going on where beds of marine algæ are continually being buried by sediment and extending their growth through and over it, thus providing a mass of sapropel such as has been shown to be capable of producing petroleum.

As regards the method by which petroleum was produced, while in the laboratory, it has been possible to produce artificial oils by destructive distillation of the different substances, the incompatibility between the condition of the rocks containing oil and the existence of temperatures approximating to those used in the laboratory render it necessary to seek some other method than that of distillation in the ordinary sense of the word. Peckham strongly supported the view that petroleum had been distilled from organic matter by metamorphic action,[1] and the heat produced by earth movements, but Orton pointed out that no evidence of the existence of even as high a temperature as 212° F. was forthcoming from any of the American oil-wells, nor in others carried to greater depths. We must, therefore, accept the general view, based upon observed facts, that time may in this matter become the equivalent of temperature; this does not, however, make the difficulty any the less in the case of terrestrial vegetation, for the total decomposition of which high temperatures and violent action are required; the character of most mineral oils themselves, moreover, precludes the possibility of their subjection to such high temperatures as are used in brown coal tar distillation.

But if we take this view, that time and pressure have produced the same effect on organic remains in the earth's crust that high temperatures produce in the laboratory, we still have to account for the differences between the oils derived from the direct distillation of animal and plant remains and natural petroleums. In Dr. Engler's experiments, already cited, he found that the oil produced by the destructive distillation of fish differed considerably from normal petroleum, particularly in the quantity of nitrogen compounds contained, but when fish oil was distilled, the product was practically indistinguishable from some forms of petroleum; in other words, when he eliminated the nitrogenous

[1] See *Proc. Amer. Phil. Soc.*, XXXVII., 108–139, 1898.

parts of the animals and dealt only with the fats, the product obtained closely approximated to natural mineral oil. In his report contained in Potonié's paper[1] on the examination of *Microcystis flos-aquæ* (Algen-Wasserblüte), a fresh-water alga from the Wann Lake near Potsdam, he found that direct dry distillation of the mass gave a tarry distillate and water, but when the whole was extracted with ether, 22 per cent. of the soluble matter was found to be "fat," and this by destructive distillation gave petroleum, showing that for plants also the nitrogenous matters should be eliminated before distillation of the product will differ notably from ordinary petroleum. Finally, attention may be again called to Phillips's experiments previously mentioned, when he allowed sea-weeds to decompose and collected the gaseous products, which contained large proportions of nitrogen and carbon dioxide, substances which do not as a rule occur largely in natural gas, and which we may suppose were derived from the cellulose of the algæ employed.

The chemical evidence cited is fairly conclusive on this point, that if marine organisms are the source of petroleum, their nitrogenous parts are in some way eliminated prior to the formation of the oil; it has already been mentioned that the fats are known to persist after the disintegration of the other material, and Dr. Engler, who first laid stress on the existence of two stages in the process of petroleum formation, and other authors have suggested a very feasible manner in which the two processes are carried out in marine deposits. In the first instance, after the death of the animal or plant, bacterial action begins, attacking the cellulose of the latter and the nitrogenous tissues of the former, but leaving the fatty matters of both at first untouched. That this does actually take place in nature was shown by Engler (see his report quoted above), who found that while the decomposing organic remains in a zoögen-phytogen mud contained 20 per cent. of fat, the living organisms contained only 15.7 per cent. The action of bacteria in the formation of petroleum was first suggested by Radziszewski,[2] and later researches have sup-

[1] *Loc. cit.*, p. 349.

[2] *Archiv Pharm.*, 3, XIII., 455–459, 1878.

ported the view that these microörganisms play an important part. Bertrand and Renault found their remains in boghead.[1] Dr. C. B. Morrey, Professor of Bacteriology in Ohio State University, found fossil bacteria in oil rocks,[2] while Meyer[3] found petroleum in a bacterial deposit from Altenberg. Some of these observers undoubtedly laid too much emphasis on bacterial action, which Lemière, who also contributed to the study of the subject, suggested[4] would be arrested as soon as the central parts were rendered antiseptic by the hydrocarbons formed. We must therefore regard the action of bacteria as in the main limited to the first stage, *i. e.*, the elimination of the nitrogenous matters, the action being automatically stopped almost as soon as the fats are attacked, while, as Engler objects,[5] soil (and sediment) acts as a bacterial filter, and so, when the action had extended to the fats, the progress of deposition would probably render these immune from further fermentation; on the other hand, he remarked that carbohydrates may be converted into fats by the agency of microörganisms.

Having then in this way accounted for the elimination of nitrogenous matters, which, as we have seen, give rise in distillation to compounds not found in petroleum, the process of transformation of fats into oil may be supposed to proceed slowly, as Phillips found did actually happen in the case of sea-weeds, while Engler and others have emphasized the fact that not only does pressure tend to raise the temperature of bodies (as Scheithauer found to be the case to a remarkable extent with lignites), but that the actions which are normally carried out in the laboratory by the action for a short time of a high temperature are equally well performed by a comparatively low temperature acting for a very long period.

[1] See Renault, *Bull. Soc. Ind. Min.*, 3, XIII., 865–1169, 1899; XIV., 5–157, 1900. Russian boghead contained *Micrococcus petrolei.*

[2] See Bull. Geol. Surv. Ohio, 4, I., 313, 1903.

[3] *Chem. Zeit.*, XXX., 814, 1906.

[4] *Compt. Rend. Congr. Geol. Internat.*, VIII., 508, 1901.

[5] *Zeitschr. angew. Chem.*, XXI., 1590, 1908.

Engler thus enumerates the various stages which in his opinion occur in the formation of petroleum from organic matter:[1]

1. Putrefaction, or fermentation, by which albumen and cellulose, etc., are eliminated. Fatty matters (and waxes), with a small quantity of other durable material and possibly fatty acids from the albumen remain.

2. Occurs partly during the first stage: saponification of the glycerides and production of free fatty acids, either from action of water or ferments, possibly both. The waxy esters are either wholly or partly hydrolyzed. The residues from many crude oils are probably due to lack of completion of these actions.

3. CO_2 is eliminated from the acids and esters, water from the alcohols, oxy-acids, etc., leaving hydrocarbons of high molecular weight containing oxy-compounds, cf. the intermediate product like ozokerite of Krämer (see p. 619) and of Zaloziecki, who also regarded that mineral as representing an early stage in the formation of oil.

4. Formation of liquid hydrocarbons and violent reaction with "cracking" into light or gaseous products = formation of protopetroleum.

He adds, in regard to all these stages, that he is assuming that time and temperature compensate one another, though pressure has no action beyond raising the temperature slightly, and is in no way equivalent to it. He considers that with moderate temperatures and pressures oil of intermediate grade will be formed, while increase of either tends to from light oils. Polymerization and addition products are formed after the completion of stage 4.

He further[2] suggests that the various hydrocarbons are formed as under:

Methanes—as direct products from the "bitumen," *i. e.*, the fats of stage 1 and heavy hydrocarbons of stage 3.

Olefines—directly formed, by splitting up of saturated chain hydrocarbons of the paraffin series,

$$C_{2n}H_{4n+2} = C_nH_{2n+2} + C_nH_{2n},$$

[1] *Zeitschr. angew. Chem.*, XXI., 1588.
[2] *Ibid.*, p. 1589.

these would afterwards polymerize to form simple methanes, etc., but they are probably partly reformed in distillation, especially at high temperatures as in the cracking process.

Naphthenes—perhaps from the decomposition of aromatic acids or esters, or from isomeric olefines under the influence of heat and pressure.

Lubricants—formed directly from the original fats, at low temperatures.

Benzenes, etc.—from the decomposition of the fats at comparatively high temperatures.

The precise part played in the reactions by the halogen compounds from sea-water cannot as yet be determined, but it may be noted that while Ochsenius considered that these bodies exerted a considerable influence, Zaloziecki regards the salts as merely tending to arrest putrefaction, a view, as it seems, more probably correct.

But while it is not difficult to account for the accumulation of the necessary quantity of animal and vegetable remains, and while feasible methods can be suggested to explain the conversion of such material into petroleum, there is yet further evidence from the natural crude oils themselves which confirms the organic theory as a whole, and materially strengthens the view that most petroleums have a dual origin from plants and animals. This evidence is derived from the study of the optical activity of petroleums to which Rakusin, Marcusson and other chemists have recently devoted much attention.

In 1835 Biot[1] found that the polarized ray was rotated by various organic substances, and amongst these petroleum; Lenz, in 1838,[2] studied the optical properties of white naphtha from Baku, but not until 1904 was the subject regarded as of great importance, when Rakusin's researches brought its meaning to light.[3] He found activity in oils both from America and Russia, and in 1906 he detected cholesterol in various oils,[4] to which he

[1] *Mem. Ac. Sci. Paris*, 2, XIII., 143.
[2] *Mem. Ac. Sci. St. Petersburg*, III., 3–12.
[3] See *Jurn. Russk. Phiz.-Khim. Obsch.*, XXXV., 554, 1904; XXXVII., 85, 221, 1905.
[4] *Ibid.*, XXXVIII. (1), 1129–1135.

suggested the property of rotation was due. He also said that the naphthenic acids possessed optical properties, but later Marcusson[1] found that these compounds when perfectly pure were inactive, and suggested that Rakusin's contained traces of cholesterol.

A word is perhaps necessary in a geological paper in explanation of the bearing of this discovery on the origin of petroleum before proceeding to a brief study of the grounds on which the optical activity of petroleums has been attributed to cholesterol. Dr. Lewkowitsch,[2] speaking of the compound, to which the formula $C_{26}H_{44}O$ is usually given, says: "It is frequently met with in the animal organism. . . . Since all animal oils and fats contain small quantities of cholesterol, the presence of cholesterol in an oil or fat points to an animal origin." At 15° C. the compound is lævorotatory in ether and chloroform solutions ($[\alpha]_D = -31.12°$). Later (p. 141), dealing with phytosterol, which has also been found in mineral oils, he says: "Phytosterol, the 'cholesterol of plants,' is widely disseminated in the vegetable kingdom, and occurs in all seeds and fruits. . . . The proportion of phytosterol in vegetable oils and fats is somewhat larger than that of cholesterol in animal oils and fats." Its optical properties are like those of cholesterol, from which, however, it can be distinguished chemically.

So, then, when the presence of cholesterol in oils can be definitely proved, their animal origin is practically certain, while it may be noted that if vegetable matter were to be regarded as the chief (or even an equal) source, we should expect to find a larger proportion of phytosterol than of the zoögen compound in petroleum. This, however, has not been found chemically and the inference is clear that in general even marine plants have played a smaller part in the formation of oil than marine animals. Apart from the chemical evidence the physical properties as regards optical phenomena furnish corroborative evidence that cholesterol (or phytosterol) is the source of the rotatory power.

[1] *Mitth. k. Mat.-prüf. Amt. Gross-Lichterfelde,* XXV., 132, 1907.

[2] "Chemical Technology of Oils, Fats and Waxes," ed. III., London, 1904, Vol. I., p. 138.

In 1904, Windaus[1] had found that by the distillation of cholesterol a product similar to petroleum was obtained, and in 1907 Albrecht[2] found that when inactive kaiser oil, mineral lubricants and vaseline were mixed together, so as to produce an artificial inactive crude petroleum, the latter when rendered active by the addition of cholesterol distillates behaved in every way like a natural active mineral oil.

Yet more definite evidence was derived from the observation of the influence of heat on the optical activity of petroleum. The greatest proportion of cholesterol derivatives was found in the highest boiling fractions and residues, but when oil was fractionated the optical activity, though comparatively feebly manifested, owing to the small quantity of cholesterol present, showed some remarkable changes in accordance with the temperature. Most oils (which are normally dextrorotatory) reached their maximum positive activity in the fractions between 200° and 300°, but the figures decreased in the portions either above or below these temperatures. Elsass oil had two maxima, the first being +0.5° (Sacch.° 200 mm.) between 69° and 76.5° under 17 mm. pressure, the second, +6.6° between 281° and 291°, under 13 mm. pressure. When Javan and Borneo oils are distilled their lower boiling fractions are lævorotatory, then they become inactive, and afterwards dextrorotatory, as shown in the following table, which represents the results of the examination of the fractions of Roengkoet oil, and is taken from Engler:[3]

Temperature C.	Pressure in mm. Hg.	Rotation Sacch.° 200 mm.
129°	16	0
129°–150°	14.5	—1.1
150°–168°	14	—2.2
168°–182°	14	—2.0
182°–242°	14.5	0
242°–268°	15.5	+1.9
268°–281°	15.5	+4.1
281°–290°	14.5–15.5	0

It was found that cholesterol when gently distilled became first

[1] *Ber. deutsch. chem. Ges.*, XXXVII., 2027–2032.
[2] "Ueber den Ursprung der optischen Aktivität des Erdöles," Karlsruhe.
[3] *Zeitschr angew. Chem.*, XXI., 1593, 1908.

dextrorotatory, then lævo-, then inactive, and finally dextrorotatory again; in other words, behaved in a similar way to Javan and other oils. If lævorotatory cholesterol is heated for one hour in a sealed tube to 350° it becomes dextrorotatory, but below 300° there is no change, and it was found that Javan oil behaved in the same way.

These results point to the existence in the oil of a racemic compound, and such a compound, with its two isomers possessing opposite activities, is found in cholesterol (or phytosterol), which on receiving the same treatment as petroleum acts in the same way. Moreover, such a theory explains the absence of activity in some oils at ordinary temperatures, which, on heating, show changing activity, as due to racemism of the contained cholesterol, the proportion of the lævo- and dextrorotatory parts being equal at first but changed by heat.

Engler also points out that the difficulty raised by some, that the supposed origin material of petroleum does not contain sufficient quantities of these compounds to cause the observed activity is easily dealt with; for the necessary quantity is small, and since in the formation of petroleum there is a loss of substance from the bodies concerned, leaving behind the parts which contain the cholesterol and phytosterol (*i. e.*, the fats), the relative percentage of those compounds in the first "bitumen" must be increased.

There seems to be no reasonable room for doubt that the optical activity of petroleum is due to cholesterol and phytosterol, since the physical and chemical properties of these bodies are both recognized in the oils, and in this way the facts constitute an important branch of the evidence. Not only do they establish beyond question the organic origin of petroleum, but also, since the alcohols in question occur in the fatty parts of animals and vegetables, it confirms Engler's hypothesis that these parts play the principal role in the formation of mineral oils.

The differences between the oils of various localities and ages has been the subject of much discussion and the exact cause of these variations is not clearly known. It may be mentioned, however, that Peckham's view, that asphaltic oils are mainly of

animal origin, while paraffin is largely derived from vegetables, is worthy of acceptance on general chemical as well as geological grounds, since Krämer and Spilker, and others, have shown that vegetable fats produce paraffin either with or without artificial distillation, and the limsetone oils, which on geological grounds are generally held to be mainly of animal origin, are notably asphaltic.

For other differences, Engler's view that variation in tempra-ture and pressure accounts for the production of hydrocarbons of different densities, etc., may be considered with that of Krämer and Böttcher,[1] that variation is due to changes after its formation, *i. e.*, polymerisation, etc., both kinds of agencies being probably potent causes. Reference may also be made to the theory of Dr. Day,[2] based on experiments on the filtration of petroleum through fuller's earth, that filtration through clays may account for some of this variation, and he suggested that the oil of Pennsylvania may be the lighter and paraffin-containing parts of the Silurian limestone oil purified by filtration through the Devonian shales. The extent to which this theory can be applied may be considered as doubtful, but that such filtration of oil does occur in nature is known, and it may be that in some fields it has taken place on a fairly large scale, without being applicable to all.

If we look back over the evidence we may sum up the position as follows:

The first main general theory, that of the inorganic origin of petroleum, has been shown to be inadmissible on chemical as well as on geological grounds, since petroleums so derived are optically inactive, differing from natural oils, while the facts of the occurrence of petroleum are opposed to the theory, and allow its application only to a few occurrences of hydrocarbons in igneous rocks where these cannot have derived their bitumen from surrounding sedimentary deposits.

As regards the theory of the derivation from terrestrial vegetation in the usual sense, the general facts on the geological side in regard to the lack of association between coal and oil are op-

[1] *Ber. deutsch. chem. Ges.*, XX., 595, 1887.
[2] *Proc. Amer. Phil. Soc.*, XXXVI., 112, 1897.

posed to it, no less than the phenomena observed in the few cases where lignites or coals and petroleum occur in association. On the chemical side, the majority of oils show no trace of the participation to any extent in their formation of land plants, and the destruction of the fibrous tissue of such organisms is, as far as is known, only accomplished by violent action at high temperatures. Where igneous rocks have penetrated deposits of buried land vegetation, some small amount of petroleum-like oil may, however, have been formed locally.

One is led therefore to regard the great majority of oils as derived from the decomposition during long ages at comparatively low temperatures of the fatty matters of plants and animals, the nitrogenous portions of both being eliminated by bacterial action soon after the death of the organism. The fats and oils from terrestrial fauna and flora may have taken part in petroleum formation, but the principal rôle must, from the nature of most petroliferous deposits, have been played by marine life. From this last we must regard the greater part of the origin material as derived, and further investigation may show more clearly the relative parts played by the zoölogical and botanical kingdoms in the process. Fruitful investigation of the question will, it may be said, be based in general upon the Engler-Höfer dual theory, now more and more generally accepted.

PROBLEMS IN THE GEOLOGY OF THE HAURAKI GOLD FIELDS, NEW ZEALAND.

A. M. FINLAYSON.

The Hauraki gold fields of New Zealand, noted in former times for the remarkable bonanzas of the Thames and Coromandel, and of late years for the progress and prosperity of the Waihi mine and its smaller neighbors, show geological features typical of the Tertiary andesitic gold fields of the Pacific and of central Europe. The district has been studied by several workers notably by F. W. Hutton, James Park, Alex McKay, S. H. Cox, J. M. Maclaren, P. G. Morgan, J. M. Bell and Colin Fraser, while visiting geologists have also written accounts of the field. The petrography has lately been investigated by Prof. W. J. Sollas in a government monograph, while the district is now being surveyed in detail by the officers of the geological survey.[1]

These gold-fields give exceptional opportunities for studying three closely related problems, namely, the nature of the propylitic facies of the andesites and dacites which enclose the veins, the causes of the oreshoots and ore-enrichment, and the source of the gold and silver. These three questions are discussed in the present paper, and it is convenient to begin with the alteration of the rocks, as the discussion of the other two points requires a knowledge of this.

I. ALTERATION OF THE ENCLOSING ROCKS.

The country-rock of the veins is a series of andesitic and dacitic lavas and tuffs, of which the dominant ferro-magnesian minerals are, in different types, hornblende, hypersthene and augite. Biotite and olivine are absent or rare. In the neighborhood of the veins the rocks are altered to a greyish-white propylitic rock, but the extent of alteration is variable, and a suite of

[1] For literature see bibliograhy at the end of this paper.

specimens showing transitions from fresh andesite to completely altered rock is difficult to procure, especially in the northern districts. Thus the alteration may be pronounced on one wall of a vein and feeble on the opposite wall, it differs in different parts of the same mine as well as in different mines, and a vein generally passes through several flows of altered tuffs and lavas of different composition, and in their completely altered state such differences may not be recognizable. In order to eliminate errors arising from these causes it was necessary to collect and examine a large series of specimens from different parts.

DESCRIPTION OF THE ALTERED ROCKS.

In the progressive change from fresh to altered rock, two general types may be distinguished: (1) a chloritised or partially altered rock (*grünstein*), which is widely distributed, and (2) the completely altered rock ("propylite" of New Zealand writers), which is confined to the neighborhood of the veins.

In the first type the ferro-magnesian minerals are replaced by pseudomorphs of green fibrous chlorite (generally penninite), while the plagioclase remains fresh or may be partially altered to carbonates and sericite. Hypersthene and hornblende are the first minerals to change, being altered to chlorite, with carbonates, granular quartz, or magnetite. Augite resists alteration to a greater degree, and may at times pass through an intermediate stage of uralite. This type of altered rock is almost universally distributed over these gold fields, unchloritized specimens being not readily procurable.

In the second type of alteration the rock becomes light-grey or greyish-white in color, the original felspars are represented by opaque white spots, and fine pyrite is scattered through the rock. The chlorite of the original dark silicates is destroyed and its place taken by carbonates and magnetite, the latter often fringed with leucoxene, while pyrite occurs in scattered grains and strings and as a product of replacement of magnetite. Pyrite also forms granular pseudomorphic aggregates occupying the place of original ferro-magnesian minerals. Siderite is abundantly developed from chlorite and magnetite, appearing as gray-

ish-brown and rather opaque masses. By reflected light the mineral is dull white and often shows its cleavage-lines. This is the species which appears to have been frequently referred in these rocks to leucoxene,[1] but an examination of residual magnetite in a specimen gave no trace of titanium, and the uniformity of low percentage of titanium in these rocks precludes the possibility of so much of the greyish-brown mineral being leucoxene. It is very similar to the siderite of the Tonopah altered andesite, described by J. E. Spurr.[2] The felspars are completely replaced by finely divided carbonates and sericite, the aggregate generally preserving the outlines of the original crystals. Secondary quartz granules are not uncommon, and at times a mosaic of fine granular quartz may replace the felspars. Valencianite (adularia), a mineral first observed in the Waihi veins by Lindgren,[3] occurs also as a secondary product in the completely altered rocks of Waihi. It forms glassy low-polarizing pseudomorphs after the soda-lime felspars, while it also occurs filling cracks and spreading into the original crystals by gradual replacement. The Waihi valencianite carries too much soda for typical adularia, and is intermediate in composition between that species and albite both of which have of late years been frequently found in association with gold-quartz.[4] The mineral was separated and analyzed by the writer, with the following result, the composition of adularia from Tonopah, and of albite (Dana) being inserted for comparison:

	S.G.	SiO_2	Al_2O_3	K_2O	Na_2O	Total
1. Adularia, Tonopah[5]....	2.57	65.52	18.59	15.44	0.45	100.00
2. Valencianite, Waihi ...	2.61	65.85	18.48	11.25	4.11	99.69
3. Albite	2.624	68.70	19.50		11.80	100.00

In view of the fact that this orthoclase is, in the specimens examined, of secondary origin, while the primary felspars are soda-

[1] Hutton, Rep. Austr. Ass. Adv. Sci., I., 1887, p. 258.

[2] "Geology of Tonopah," Professional Paper No. 42, U. S. Geol. Survey, 1905, p. 248.

[3] *Eng. and Min. Journal*, 79, 1905, p. 220.

[4] W. Lindgren, "Orthoclase as a Gangue Mineral in Fissure-veins," *Am. Journ. Sci.*, 4th ser., Vol. 5, 1898, p. 418.

[5] J. E. Spurr, *loc. cit.*, sup., p. 87.

line varieties, the original rocks appear to have been in the main dacites and andesites. Prof. Sollas, however, has classed some specimens as altered pyroxene rhyolites and trachytes,[1] and it should be noted that fresh rhyolites do occur in some parts of the southern district, with the more basic rocks. The presence of soda in the Waihi valencianite is doubtless due to its derivation from soda-felspars by the action of the potash-bearing vein-solutions.[2] Mr. P. G. Morgan has identified two lime-bearing zeolites, stilbite and laumontite, in the altered rocks of Waihi where they occurred in cavities and as small veinlets.[3] They have doubtless been formed at shallow depths during the destruction of the soda-lime felspars.

The groundmass of the completely altered rocks is composed of finely divided carbonates, sericite, pyrite, and more or less secondary quartz. Progressive silicification is very marked at Waihi. Epidote is not very characteristic of these rocks, which differ in this respect from Rosenbusch's type-rock. The mean specific gravity of fresh hornblende-andesite from the Thames is 2.688, that of the completely altered rock is 2.312.

NOMENCLATURE.

The history of the term propylite in petrographic nomenclature is now familiar and need be recounted. Its use as a term descriptive of the thermally altered phases of andesitic rocks on Tertiary gold fields has been abandoned, notably by Lindgren,[4] Spurr,[5] and Von Inkey,[6] on account of the varying nature of the altered rock in different districts, while its etymology, dating from a time when age-difference became a basis of rock-classification, is equally open to objection. The term propylitic facies,

[1] "Rocks of Cape Colville Peninsula," Wellington, 1906, II., pp. 17–19, and 67.

[2] The possibility of secondary orthoclase was suggested for these rocks by Dr. Malcolm Maclaren (*Gold*, London, 1908, p. 315).

[3] *Trans. Austr. Inst. Min. Eng.*, 8, 1902, p. 186.

[4] *Trans. Amer. Inst. Min. Eng.*, 33, 1903, p. 798.

[5] Professional Paper No. 42 (Tonopah), U. S. Geol. Survey, 1905, p. 236.

[6] Internat. Geol. Congress, sess. 10, Mexico, 1906, Vol. I., p. 508.

however, retains its significance as applied to the general type of altered rock. Zirkel's use of the term propylite as a primary rock type—a deep-seated representative of dacite-porphyrite and diorite-porphyrite, has not met with general acceptance.

In New Zealand, the use of the term propylite on the Hauraki gold fields was advocated by Prof. J. Park,[1] and the word was commonly used in the former reports of the New Zealand Geological Survey. Prof. Sollas, however, in his monograph on these rocks, accepts Zirkel's definition of propylite, so that an unfortunate confusion of terms has arisen. Again, New Zealand writers applied the term to the completely altered rock (sericite-pyrite-carbonate rock), whereas Bela von Inkey defines the propylitic facies as chloritized andesite (grünstein). In the face of these and other confusions arising from the varying use of the term, and the varying nature of the altered rocks to which it has been applied, it is obviously advisable to abandon the term.

PRODUCTS OF WEATHERING.

The altered rocks in general are very susceptible to the action of surface-waters in the neighborhood of the vein-fissures. Under these conditions the rocks become soft, earthy, and iron-stained, with destruction of pyrite. The two chief products resulting are abundant kaolin and iron oxides. The unweathered rocks are free from these products, kaolin being not a product of alteration by the vein solutions on these goldfields. This bears out the statement of Lindgren that kaolin does not generally occur with carbonates and sericite formed by metasomatic processes.[2]

Chemical changes.

1. *Thames.*—The following analysis of a series of specimens from the Halcyon mine, illustrate the changes in the various constituents.

[1] "Geology of Hauraki Goldfields," *Trans. N. Z. Inst. Min. Eng.*, I., 1897, p. 25.

[2] "Metasomatic Processes in Fissure-veins," *Trans. Amer. Inst. Min. Eng.*, 30, 1900, p. 614.

	1	2	3	4	5
SiO_2	57.42	52.69	57.99	55.38	58.98
Al_2O_3	17.61	18.33	17.59	15.63	11.21
Fe_2O_3	2.34	2.32	1.56	1.88	1.45
FeO	3.77	2.98	2.37	2.95	2.42
MgO	2.19	3.09	2.01	1.88	1.43
CaO	5.69	7.87	5.45	6.01	8.11
Na_2O	3.22	2.62	1.98	0.83	0.61
K_2O	1.94	0.98	1.65	3.28	3.93
H_2O-	0.85	0.73	1.56	2.41	2.54
H_2O+	2.62	3.71	1.89	1.92	1.15
TiO_2	0.68	0.53	0.51	0.24	0.11
CO_2	0.95	3.59	3.89	4.58	4.69
P_2O_5	0.31	0.42	0.35	0.11	0.06
MnO	0.43	0.25	0.21	0.23	0.11
FeS_2			1.42	2.35	3.13
Total	100.02	100.11	100.43	99.68	99.93

1. Fresh hornblende andesite, Thames.
2. Chloritized hornblende andesite, Halcyon mine.

Sericite-pyrite-carbonate rock.
3. Altered andesite, 14 feet from Ophir vein, Halcyon mine.
4. Altered andesite, 5 feet from Ophir vein, Halcyon mine.
5. Altered andesite, adjoining Ophir vein, Halcyon mine.

(3–5: 386 feet level.)

The progressive changes in the constituents may be summed up as follows: With chloritization of the hornblende there is a preliminary loss of silica, which is afterwards restored, but there is no marked net change in this constituent. Alumina, along with titanium and phosphoric oxides, is reduced in the rock close to the vein. The loss of iron oxides is more than balanced by the formation of pyrite. There is a loss of soda and gain of potash, characteristic of the propylitic type of alteration. Magnesia is also reduced, with a corresponding increase of lime, and the rock has gained much carbon dioxide, chiefly in the chloritic phase of alteration.

In the vein-zone the waters were evidently rich in potash and poor in soda, and suffered a depletion of the former and addition of the latter by their interaction with the feldspars and the formation of sericite and adularia. The solutions must have been highly siliceous, but the bulk of their silica was deposited in the

fissures, there being no marked silicification of the adjoining rocks.

2. *Waihi.*—The next series of analyses, of specimens from a cross-cut to the Empire vein, Waihi Mine, shows the extensive replacement and silicification of the rocks, which has been very marked during vein-formation at Waihi, and which is similar in this respect to the processes of vein-formation at Tonopah.[1]

	1	2	3	4	5	6
SiO_2	63.45	58.39	61.78	69.35	76.61	85.65
Al_2O_3	15.26	16.51	14.89	11.66	8.31	1.35
Fe_2O_3	2.28	2.46	2.08	1.53	1.08	0.43
FeO	3.01	2.98	2.51	1.66	0.59	0.21
MgO	1.29	1.66	1.08	0.46	0.51	0.31
CaO	3.44	4.08	3.16	2.09	3.61	2.56
Na_2O	2.21	2.08	2.18	1.06	0.29	0.28
K_2O	1.78	2.89	3.68	3.31	1.98	1.41
H_2O-	1.10	2.41	1.89	1.61	0.43	0.24
H_2O+	2.90	2.87	3.05	2.12	1.08	1.33
TiO_2	0.75	0.68	0.69	0.43	0.28	tr.
CO_2	1.08	1.56	2.01	2.24	1.87	2.04
P_2O_5	0.29	0.31	0.30	0.26	0.11	tr.
MnO	0.36	0.32	0.28	0.11	0.11	0.12
FeS_2			0.65	1.88	3.59	4.69
Total	99.20	99.20	100.23	99.77	100.45	100.62

1. Fresh hornblende dacite, Waihi.
2. Chloritized hornblende dacite, 45 feet from Empire vein.
3. Altered dacite, 30 feet from Empire vein.
4. Altered dacite, 15 feet from Empire vein.
5. Altered dacite, adjoining Empire vein.
6. Replacement-ore, Empire vein.

} 850 feet level.

Taking the series from No. 1 (fresh dacite) to No. 6 (replacement-ore), it will be noticed that silica is reduced and carbon-dioxide increased in the chloritized type (No. 2), exactly as at the Thames. Subsequently, silica shows a steady increase, culminating in the highly silicified rock which composes much of the vein-material (No. 6). Alumina, together with titanium and phosphoric acids, has been reduced notably in the neighborhood of the veins. The progressive loss of iron oxides is accounted for by the metasomatic formation of pyrite. Magnesia has been reduced, but lime has not on the whole been greatly af-

[1] J. E. Spurr, *loc. cit.*, sup., p. 216.

fected. There is a notable loss of soda and gain of potash, except near the vein, where the potash has also been reduced with the intense silicification.

Thus at the two localities selected for examination—Thames and Waihi—the processes were similar, except for the notable silicification at Waihi, and the more intense carbonation at the Thames. In this connection it is worthy of note that great volumes of carbon dioxide were encountered in several of the Thames mines.[1] The gas evidently represents a residuum which escaped from or was left by the vein-forming solutions, and enclosed in cavities in the veins during their filling.

AGENTS OF THE ROCK-ALTERATION.

The microscopic evidence as already mentioned, shows two types of altered rock, namely, the chloritic type, found almost universally over the whole of the gold fields and not confined to vein-bearing areas, and the completely altered sericitic type, confined to the neighborhood of the veins. The chemical evidence also indicates that the processes of alteration in these two rocks were different. In the first there was a loss of silica and a gain of carbon dioxide, which latter was presumably the agent in the formation of chlorite. The waters in this case, then, were poor in silica and highly carbonated. In the second rock there is a loss of the refractory base, a considerable loss of soda and gain of potash, and introduction of sulphur. The solutions were here rich in potash, sulphur and silica. The differences in the solution, as shown by their effects, do not seem readily explicable by gradual changes in their composition as they circulated laterally from the vein-fissures into the country-rock. Moreover, the widespread alteration of the ferro-magnesian silicates could scarcely have been accomplished by the circulation (of waters) through the great extent and thickness of the solidified rocks, either before or after the period of vein-formation, and this chloritic facies of andesitic rocks is found in many volcanic districts devoid of mineral veins or other evidence of hydro-thermal processes.

[1] Jas. Park, *Trans. N. Z. Inst. Min. Eng.*, I., 1897, p. 23.

The most reasonable explanation seems to be that the chloritization took place immediately after the eruption of the rocks and during their solidification, through the agency of contained solutions or gases rich in carbon dioxide, which is such a characteristic product of volcanic action. In this connection it is noteworthy that the hornblende often shows a resorption border or reaction-rim of chlorite and magnetite, probably due to reactions with gases which saturated the rock during or immediately after the separation of the crystals.

The formation of the sericite-pyrite-carbonate rock, on the other hand, is certainly due to the vein-forming solutions which were at first rich in silica and potash, but became impoverished in these constituents, and gained soda as they seeped into the rocks immediately adjoining the vein-fissures. The corresponding effect on the rock was a concentration of potash and a leaching of soda.

GRAPHIC REPRESENTATION OF CHANGES.

The chemical changes are illustrated by the following diagrams constructed in accordance with W. H. Hobbs's modification of Broegger's method,[1] the arms being drawn proportional to the molecular ratios. The first two diagrams, Figs. *a* and *b*, Plate VIII., constructed from the Thames analyses, show the change from fresh andesite to the chloritic modification. The third and fourth, Figs. *c* and *d*, Plate VIII., from the Waihi analyses (Nos. 1 and 6) show the change from fresh dacite to replacement-ore by silicification.

EVIDENCE FROM THERMAL SPRINGS.

J. E. Spurr has pointed out that thermal springs, having risen through a considerable thickness of rocks, may be expected to have a composition analogous to that of the vein-forming waters after they had penetrated laterally some distance into the rocks.[2] Analyses of springs in typical New Zealand thermal districts,

[1] W. H. Hobbs, "Classification of the Igneous Rocks," *Journ. Geol.*, 8, 1900, p. 1.

[2] *Loc. cit.*, sup., pp. 237–238.

PLATE VIII.

FIG. a.

FIG. b.

FIG. c.

FIG. d.

recorded by W. Skey[1] and J. S. Maclaurin,[2] show generally poverty of silica, and nearly always a great excess of soda over potash. A similar state has been inferred in the case of the vein-forming solutions on the Hauraki goldfields, after they had passed into the country-rock from the vein-fissures. The present mineral springs have therefore evidently suffered a continual loss of silica and potash in their ascent and gained soda from the walls of their circulation channels. It is worthy of note that the siliceous sinters of Rotorua contain appreciable quantities of gold and silver.[3]

2. ORE-SHOOTS AND ORE-DEPOSITION.

The veins of Hauraki are broadly divisible into two types—a northern and a southern.

NORTHERN TYPE.

These veins, occurring in the Thames and Coromandel districts, are generally small, and carry bonanzas in irregular shoots of often phenomenal richness. The vein-filling is chiefly massive or comby quartz, the gold is typically coarse and free, with a fineness of from 680 to 700, and is accompanied by pyrite, arsenopyrite, and other sulphides. The bonanzas are separated by low grade or barren portions of the veins, which are generally poorly mineralized. The bonanza-zone extends to a depth of from 400 to 600 feet below the present surface. At greater depths the veins have seldom been found payable, although there are indications at Coromandel of a lower zone of similar but less rich bonanzas,[4] as at Cripple Creek.[5] The ore-shoots are closely dependent on faults, vein-intersections, and leaders. Lindgren concludes that the ore-shoots are of primary origin,[6] but Morgan inclines to the view that they have resulted from secondary en-

[1] *Trans. N. Z. Inst.*, 10, 1877, pp. 423–448.
[2] 39th Ann. Rep. Col. Lab., Mines Dept., N. Z.
[3] J. M. Bell, 1st Ann. Rep. N. Z. Geol. Survey, 1907, p. 6.
[4] Fraser, Bull. No. 4, N. Z. Geol. Survey, 1907, p. 100.
[5] Lindgren and Ransome, P. P. No. 54, 1906, p. 207.
[6] Lindgren, *Eng. and Min. Journal*, 79, 1905, p. 219.

richment by descending waters.[1] Microscopic examination of the rocks, however, shows that the bonanza zones, although occurring comparatively near the surface, are always enclosed by highly altered andesites, while poorer portions of the veins are frequently associated with comparatively fresh country-rock. This feature is difficult to explain by the action of descending waters, as the rock-alteration is clearly due to ascending thermal solutions. The petrographic evidence, therefore, is in favor of the view that the localization of the ore-shoots is primary, and due to deposition by ascending solutions in a zone rendered "critical" by extensive fissuring with consequent relief of pressure, the ores being continually augmented by the cumulative effects of mass-action. At the same time, it is difficult to account for the extremely rich bonanzas except by processes of secondary enrichment, and it seems highly probable that descending waters have subsequently played a considerable part in the concentration of the ores.

SOUTHERN TYPE.

These veins are typically developed at Waihi and Karangahake. At Waihi[2] the veins are of great width, while the ore-shoots are very uniform and continuous. The free gold is generally invisible and has a fineness of about 645. Near the surface the vein-material is a typical siliceous sinter, oxidized, but not appreciably enriched. At greater depths this is gradually replaced by primary sulphide-ore, composed of finely crystalline quartz, with a little calcite and valencianite, and impregnated with finely divided pyrite, argentite and blende. The gold values occur mainly in the pyrite, and the ratio of gold to silver in the ore is 1 : 6. This sulphide-ore is typically a product of replacement of the country-rock, as has been seen in the analyses discussed above, and this is also evident from the manner in which the veins shade off by degrees into barren rock, without any defined walls. Under the microscope the vein-material appears as a fine mosaic of granular quartz, with occasional pseudomorphs of adularia, and patches

[1] Morgan, *N. Z. Mines Record*, 8, 1905, p. 465.
[2] Bell and Fraser, *Canadian Min. Journ.*, 29, 1908, pp. 388 and 420.

of carbonates and sericite, the whole impregnated with grains and strings of sulphides.

In the deeper levels this replacement-ore is frequently traversed by numerous parallel strings and veinlets of quartz, argentite and pyrite, giving a finely banded appearance to the ore. This banded sulphide-ore, carrying gold to silver in the ratio of 1:30, constitutes some of the richest ore mined at Waihi. The suggestion that it may be due to a later period of mineralization than the original replacement-ore,[1] is confirmed by microscopic examination. This shows it to consist of close-set parallel strings of quartz, often banded and comby, alternating with seams and strings of pyrite and argentite. Examinations of the adjoining rock shows that it also is traversed by numerous veinlets of quartz and sulphides, of later date than the alteration of the rocks.

There have thus been at Waihi and in similar districts, either two successive periods of mineralization, or else a prolonged period of mineralization, during whcih the character of the ore deposited underwent a change. The earliest phase was characterized by extensive silicification and replacement of the adjoining rocks, and to this the great width of some of the veins is chiefly due. The later phases were marked by the deposition of more highly argentiferous ore along portions of the veins which had been partially reopened or fractured by movement, and had thus given access to the solutions. The alteration of the rocks was effected during the earlier stages, the products then formed being stable and unaffected by the circulation of subsequent solutions. The later mineralization accounts for the uniform and often improved value of the ore in depth, and as the highest level of deposition was then apparently at a considerable depth beneath the outcrop, the deep zone which has been thus enriched may reasonably be expected to persist for some depth to come.

3. SOURCE OF THE PRECIOUS METALS.

Bela von Inkey has recently, while emphasizing the universal association of grünstein (propylitic facies) with the tertiary an-

[1] *Id., ib.*, p. 420.

desitic gold fields, called attention to the desirability of further chemical examination of the fresh rocks for gold and silver, and suggested that the metals were originally contained chiefly in the hornblende, from which they were leached out by the solutions which at the same time effected the chloritization.[1] But the same widespread alteration of andesites is found in regions where there are no gold-veins. The view that the ores of Hauraki were derived from the surrounding andesites was advocated by F. W. Hutton,[2] but Dr. J. R. Don, after a series of exhaustive tests, failed to find gold in the unaltered rocks.[3] Further, assays now in progress in the laboratory of the New Zealand Geological Survey are stated to be in confirmation of Don's results.[4] It may possibly be found that the unaltered ferro-magnesian silicates of these rocks do contain traces of gold and silver, a matter which the writer has not had the opportunity to investigate. Even, however, with that fact established, the theory that these silicates were the direct source of the ores in the veins encounters great difficulties, since it seems most probable that the solutions which effected the chloritization of the ferro-magnesian minerals were active during the consolidation of the successive flows, and gradually escaped upwards under low pressure, whereas the solutions which mineralized the veins rose from considerable depths at a distinctly later period.

It seems most reasonable, in the case of gold-fields of this type, to conclude that the rocks arose from a magma, in which or in portions of which the metals were segregated, and from which they were subsequently transported in solutions freed by the formation of fissures in the overlying solidified lavas and tuffs.

The writer is indebted to Mr. Colin Fraser of the New Zealand Geological Survey, for a series of rock-specimens from the Thames, and to Professor W. W. Watts of the Imperial Col-

[1] B. von Inkey, "La relation entre l'état propylitique des roches andésitiques et leurs filons mineraux," Internat. Geolog. Congress, sess. 10, 1906, Vol. I., p. 501 et seq.

[2] Rep. Austr. Assoc. Adv. Sci., I., 1887, pp. 245–274.

[3] J. R. Don, "Genesis of Certain Auriferous Lodes," *Trans. A. I. M. E.*, 27, 1897, p. 564 et seq.

[4] Bull. No. 4, N. Z. Geol. Survey, 1907, p. 107.

lege of Science, London, for granting facilities in the laboratory and for suggestions and criticisms.

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DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE CLASSIFICATION OF GEOLOGIC MATERIALS.

Sir: Each specialist in the geologic field, in writing reports, finds it natural to classify his material on some basis, to clarify the discussion, but it seems that some men feel that they will not be given credit for any new results in their work, unless they invent a new method of classification. This tendency has led to a deplorable state, in that it is often desirable to compare two men's results and difficult unless they have used the same basis of distinguishing classes. It is not intimated that a classification should be stable,—it will undoubtedly be constantly developing. However, it appears that some attempts, seemingly made for the sake of variety, use a basis that is open to criticism in other points, besides that of adding confusion to the study. If so, may we not eliminate them?

As an introduction to the subject reference may be made to some extensive remarks by Alfred Harker in his recent book on the "Natural History of Igneous Rocks." As an extreme view of classification he quotes Pinkerton as saying: "The only advantage of every methodic system in Natural History is to assist the memory." He contrasts with this his own thought, which may be stated, if correctly understood: Scientists at present aspire to a natural system of classification, which shall represent the true relationships of the various types. It appears from his discussion that a natural, true and essential relationship must be

genetic; and, hence, quite analogous to the basis of classes in the organic world.

A glance at the systems used for various geologic materials will reveal how little this principle is adhered to and at the same time reveal at least a part of the reason. The materials under discussion are, broadly, rocks; with related groups of minerals and fossils, and sub-groups of coal, clay, ore deposits, waters, etc. The primary division of rocks is genetic in principle, but the list of criteria used for further divisions is quite extensive.

CRITERIA USED IN CLASSIFICATION.

1. Age		Rocks.
		Coal.
2. Geologic association and position		Minerals.
3. Uses		Coal.
		Clay.
		Water.
4–A. Mineral composition	Mineral content	Rocks.
4–B. Chemical properties	Composition	Minerals.
		Coal.
		Clay.
		Rocks.
		Water.
	Weathering	Coal.
	Temperature	Water.
	Heat of combustion	Coal.
	Volatile matter	Coal.
	Hardness	Clay.
	Plasticity	Coal.
5. Physical properties	Fusibility	Coal.
		Clay.
	Form and occurrence	Rocks.
		Minerals.
		Ores.
		Fossils.
	Structure and texture	Rocks.
		Fossils.
6. Method of genesis		All.

Particular examples show why the subdivisions are not based on genesis. A clay may be classed as a sediment, or a weathered alteration product without conveying any clear impression to distinguish it from the other type. Clays that originated by certain

processes may be quite unlike. Clays that originated by rather different processes may be quite similar. The last step in the origin of a rock is usually the only recognizable one. Subdivisions on the more remote origin are seldom possible. Among igneous materials the solidification from fusion is the recognizable origin, and it is only by long, careful search that we sometimes discover the nature and other differentiation products of the parent magma. Among sediments the same sort of difficulty prevents the use of origin for subdivisions.

The demand for genetic classifications seems to arise largely from the successful use of such a basis in biology, developing, as it did from the evolutionary ideas. Early science compared form and appearance, but biologic advance soon found the structure more essential than the form. The method of generation, the evidence of common ancestry, and all the factors summed up in origin, gained prominence as evolution was set up as a working theory. But the geologic problem differs essentially from the biologic.

1. Most of the material is composed of minerals (chemical compounds) which lose their identity when change or evolution occurs, while a biologic cell may be considerably changed and still be the same cell. The physical and chemical character of the first piece of quartz formed must have been much the same as that of the present material studied.

2. The nature of the evolution of rocks and their origin is highly complex, the products often extreme, the process often inaccessible and the record of the process hard to interpret from present forms and processes.

3. Results show all gradations between present extremes and common ancestors.

It therefore seems an open question, how far to retain genetic characters, as Harker pleads, in subdivisions of classification. Equally open is the question as to the logical selection of other bases of subdivision. There is certainly an extreme variety in the attempts made to classify some materials; clay, for example. The multiplicity is confusing to a beginner in the special study. Each specialist has found it necessary to modify or invent classes

for his own work. For every new point of view a new classification is proposed, and some systems are hardly worthy of the name. All this seems unnecessary. The biologists have not proposed new classifications lately; even if some specialist listed all the red flowers and all the yellow ones, he did not propose a system based on color. It seems that some rules might be formulated for controlling the factors used and eliminating some needless complication. It is suggested further, that most efforts in the past have been analytical, discussing a field so broad that no one man could be thoroughly familiar with the whole, while the ultimate solution will probably be synthetical and will remain unstated till some one collects the work of many specialists, each familiar with thousands of varieties in his own special sub-group. In most systems the divisions have not yet reached the degree of "species" in a sense comparable with biologic or paleontologic species. "Granite" may include scores and possibly hundreds of species. When the student of granite knows approximately all the possible variations he can establish the natural lines of division and whatever arbitrary ones are advisable. Again, after many thousand variations in a shale are carefully described, some specialist may estimate about what the possibilities are for shale in this planet. Such work may be the foundation of the synthetic classification.

Past efforts may be grouped as commercial, scientific, or attempts at compromise. In addition, we have those so-called classifications, which are of simply local interest, and group those materials possessing a certain property without regard to distinctions or similarity in other respects. The commercial system is invented by the men who use the material, or live by its exploitation. They classify clay by the use they make of it, coal by its action in the fire, ore deposits by their form, occurrence and the treatment the ore needs. On the other hand, the development of the classification of igneous rocks was primarily a matter of scientific, rather than commercial interest. Without stopping for other possible examples, we may consider the systems proposed for special objects. The grouping of coals on the basis of heat of combustion does not distinguish anthracite from soft

coal, though they are clearly distinct. It might be favored where the coal was of high fuel value, but could hardly be accepted as a general scheme. Emmons[1] has recently proposed a classification of minerals from a genetic standpoint. In this the eight classes are admitted to cover only a part of the conditions under which minerals grow, and in the name or description of the classes the *position* is given as the basis of the class, with evident assumption of relation between genesis and position. It has many elements of value and the writer is in no position to criticise its essential points, but it is another example of a system, not of general application, but chiefly of interest in the study of ore deposits; not an advance in the science of mineralogy, but an application of a branch of that science to a special problem. Not a class is suggested, but it is found that the minerals assigned to it are chiefly found in the other seven classes. Possibly the difficulty is a matter of words only. Would it not be wise to restrict the use of terms so that "class" and "classification" are retained only for those systems based on distinctive criteria, and leave the word "group" for such compilations, or simply speak of a comparative study? Classes that overlap seriously can usually be avoided by proper selection.

It is evident, on a moment's thought, that it is to the economic geologist that we owe many of the systems now in use. As a scientific worker in a commercial field, he has several possible courses: (1) Use of the commercial, or some early defective system with an attempt to give it a scientific basis; (2) abandonment of old systems and construction of new; (3) compromise; (4) neglect of all classification. Even the scientific workers find the same choice necessary as new knowledge comes to them. Definitions are revised; old names may be retained, yet have added significance. Different workers chose differently in this situation. No rule can be stated to cover all cases.

Before considering examples a word is needed as to the method of determining classes, which may not be identical with the basis of classification. The origin of a rock is usually indicated by its

[1] This Journal, 3, 611.

structure and texture—physical properties. It is seldom that a man who sees the formation of a large rock mass has a chance to study the product, but the few cases studied have shown the relation between these physical properties and genesis. Similarly a classification based in its nomenclature on a physical property may be determined by a chemical test. A new development in the way of tests or methods may prove the new method to be closely related to the property involved in the classification. Such discoveries are always noteworthy and their value increases as they (1) correspond accurately with the basis of classification, (2) become well known, and (3) are simple and easy.

Several recent workers on the classification of coal have attempted to give an accurate basis for the commercial classification that is so well known and widely used. Inasmuch as the commercial method depends on a man's judgment of the action of a coal in the fire, which depends on the fire-box; and of the color, which shows all grades from brown to black; and of the structure, which shows all grades from woody to amorphous; it is surprising that any accurate tests could be discovered, showing as few exceptions as those proposed. With quantitative tests agreeing with such a large proportion of commercial estimates it would seem that the tests might be relied upon, and the public educated to agree with science in the few doubtful cases.

The recent quantitative chemico-mineralogical classification of rocks is an illustration of quite complete abandonment of old methods for distinctly new ones. In spite of criticisms it does draw a line between groups and brings out some very essential and fundamental qualities, if not genetic ones. The best accepted classification of natural waters is chemical, but no such classification is yet on a quantitative basis.

Ore deposits and clays are often arranged in groups that seem to be compromises of doubtful value. Radically different proposals have been made, however, some entirely genetic, some entirely commercial.

In some cases the difficulties are so numerous that it may be questioned if there can be any system satisfactory to both the

science and the trade. The following is from a discussion of the waters of Illinois.[1]

"These classifications (just outlined) are faulty, in that various divisions are not sufficiently distinctive and many waters could be placed in two or more classes." The one or two methods which eliminate this defect are then given, but "it is difficult to find a classification that will answer the requirements of all interested parties." All methods are abandoned in the report and analyses are given with only a geographic arrangement.

No doubt other geologic materials yield other results, and the specialists in various lines assume different attitudes toward the question. The field geologist is probably most insistent upon a genetic classification. The paleontologist is indifferent to all except the biologic classification of fossils. The mineralogist has a rather exact classification based on chemistry, crystallography and physics, which is so satisfactory that he is inclined to use chemical and physical tests for other materials; possibly including a mineralogical statement of the chemical work. Any laboratory worker finds it necessary to classify material furnished him in small bulk, and inclines toward similar tests. The practical miner, however, prefers the use of form, occurrence, or necessary treatment. Is there not some possible generalization by which individual viewpoints may be mostly eliminated? The following are suggestions which will bear discussion:

A SUMMARY OF SUGGESTIONS.

1. Those arrangements of materials which yield largely overlapping groups, and those which have as distinguishing characters a property incapable of quantitative expression, should not be called classifications.

2. *All bases should be capable of quantitative determination, or exactly related to some property capable of such a test; so that, if no natural groups are found, an arbitrary line may be drawn to limit the classes. The best basis for classification should involve inherent and fundamental qualities of the materials con-*

[1] Edward Bartow, Bulletin 10, Illinois Geol. Survey.

sidered. Allied to this is the requirement that advantage should be taken of any natural grouping. As a further help in selection, the basis or test should be easily applied, widely known, and have a wide range of values in the material classified.

3. If no such classification exists the choice of action depends entirely on the material concerned, always aiming to follow the above points in the classes finally used.

4. In discussion of concrete examples of the criteria available, we find *age* generally discredited, and *uses* and *geologic position* producing many overlapping groups. There are left the *physical* and *chemical properties* and *method of genesis.* The contention of Harker, that the genetic characters are more inherent and fundamental than the chemical and physical, is open to question. As far as composition is more fundamental than method of genesis, it is to be preferred. Some physical properties are also quite essential and those which are capable of quantitative measurement may be used if they also conform to the suggestions in paragraph 2 above.

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October 26, 1909.

THE CLASSIFICATION OF COAL.

Sir: In considering this question I assume the correctness of the statements given in the preceding paper as suggestions. I will be ready to abandon the position when the tendency of geologic opinion is clearly opposed to them.

1. We are not dealing here with any grouping for special study of some minor problem, but with a general, comprehensive and scientific classification of coal. The groups must be selected to avoid overlapping as far as possible. Coals clearly distinct must not be left together.

2. The origin is discussed by Dr. David White,[1] but it seems we still know too little to make good use of genesis as a basis of classes.

[1] ECONOMIC GEOLOGY, 3, 292.

3. Aside from this, the physical and chemical properties of a coal are its most fundamental characters. The selection of the particular properties to use must be made on definite principles. The property must primarily be capable of quantitative expression. It should take advantage of any natural grouping that exists. It should, if possible, be easy and accurate of determination.

4. The commercial classification has become so well known and widely used that it can hardly be necessary to drop it. Modifications, like that of the U. S. Geological Survey, in dropping "black lignite" and using "sub-bituminous," are quite desirable as the writer previously suggested.[1] The writer has seen no statement by the survey defining the new term very accurately, however. It is "next below the grade of bituminous," and above the brown lignites.

5. In devising tests for quantitative determination of groups, those tests should be selected which disagree least with the commercial classification, or such modifications of it as the sub-bituminous class above mentioned. However, if there are a few exceptions, even in the best known method, it is not at all necessary to discard all tests of quantitative nature, and that method should be selected (other things being equal) which has the minimum number of exceptions.

The writer's effort has been to select such a method and his only excuse for new methods is the possibility of a smaller number of exceptions. The basis of criticism of several recent methods is not only that the line between soft coal and lignite is uncertain, but that no position is provided for cannel coal; this being left to fall with either lignite or semi-anthracite, which differ widely. The class is not abundant, but is a clearly defined type and has a large intermediate group—the "semi-cannels." Every analysis of such coal forms an exception to the proposed methods, and it is to be hoped that more cannel coal will soon be tested than has been heretofore. No such coal is included in the U. S. Survey reports of recent work, though some of the types selected are equally rare. All the methods which depend upon a single ratio for classification must fall into some such error as this.

[1] ECONOMIC GEOLOGY, 2, 239.

The various workers justify their use of such incomplete systems by local convenience. A West Virginia geologist approves Dr. David White's[1] plan of arrangement by ratio of carbon to the sum of ash and oxygen, because the scheme agrees closely with the calorimeter in arranging coals in their natural order of excellence as fuel. But as Professor Parr[2] remarks, "the element of *worth* should not dominate the idea of classification," and outside that state where coals have such high fuel value few students would see any advantage in such an arrangement.

The writer's suggestion is not the only one to avoid these criticisms. Parr's[3] and Seyler's[4] are quite capable of good results in providing for cannel and lignite. I know of no comparative study of the disagreements between these and the commercial classifications, but I have given in my first paper the reasons for my choice and they still seem sufficient; and I hesitate more than ever to use oxygen, or the inert volatile matter dependent upon it, since Professor Parr[5] has shown the probability of past errors in its estimation. Possibly his warning may improve the accuracy of future work, but it makes it more complex. I have not hesitated, as Seyler did, to use the estimation of fixed carbon and volatile matter. Admitting that the results depend on conditions, I still think the method as standardized by committee report is sufficiently accurate for the anthracitic end of the coal series. No doubt still other tests may be suggested and it must be left for the greatly increased data, probably to be available in the next few years, to settle upon the most satisfactory.

One test, distinguishing two very different types of coal, is still in very unsatisfactory condition. Coking and non-coking coals are classed together in most systems, and are distinguished in the laboratory by their action when heated in a covered crucible, but it is not easy to state quantitatively the difference in the action of the two types and work on this problem is much needed.

[1] *Science*, N. S., **27**, 537.
[2] *Jour. Am. Chem. Soc.*, **28**, 1430.
[3] *Jour. Am. Chem. Soc.*, **28**, 1425.
[4] *Proc. S. Wales Inst. Eng.*, **21**, 483, and **22**, 112.
[5] *Jour. Ind. and Eng. Chem.*, **1**, 638.

If I may be permitted to reply to Mr. Collier's criticism, without appearance of quibbling, I can point out one or two peculiar statements. He says: "To illustrate the failure" (of the Grout method) "the following analyses are given." He then gives seven lignite analyses which illustrate the complete success of the method rather than its failure. Following these are twelve analyses under the heading sub-bituminous, and of these, six also are properly placed by that method. Only six out of nineteen results appear to be exceptions to the method, and a few words may be said concerning these six.

Of the Philippine coal I know nothing, but it can be assumed to be similar to the others. Concerning sample 1,680 (U. S. Geol. Surv.) from Tesla, California, the mine superintendent writes me: "It has always been considered lignite and sold as such." Parts of the bed are black and lustrous like glance coal, but the commercial product behaves as lignite. F. W. Clarke in Bulletin 330 (U. S. Geol. Surv.) uses an analysis of the Tesla product as illustrating typical lignite. The other coals of the six apparent exceptions are from Montana. Sample 3,704 is from Custer County, a region from which Collier and Smith[1] describe both lignite and coal in the higher and lower horizons, but the state reports speak only of lignite,[2] clearly following its local reputation. Similar disagreement is found in these bulletins regarding the Chouteau County fuel, samples 6,315 and 6,609. The other two apparent exceptions are samples of coal from Red Lodge, Montana, which is apparently too good to call lignite, though Clarke places it there with a question. It is noteworthy in the case of Red Lodge coal that the *average* of the results known places the coal above lignite, though the variation is quite across the line drawn to divide the groups. The secret of these exceptional cases appears to be given in a statement made by one of Mr. Collier's associates, Mr. Woolsey, in Bulletin 341 A. "The differences" (in the analyses from a single bed) "are probably due to the fact that the samples represent different stages in the deterioration of the coals, consequent upon their

[1] U. S. Geol. Survey, Bull. 341 A, p. 34 et seq.
[2] University of Montana, Bull. 37, Jesse P. Rowe.

exposure to the deleterious effects of the elements." He offers this suggestion to explain a variation in the per cent. of carbon in pure coal, from 67 to 76, quite across the line I gave for the distinction of coal and lignite. His field data no doubt confirm his conclusion.

Now, when Mr. Collier states that these coals are black and have little woody texture, and includes Custer County, Montana, and the Tesla, California, samples, I submit there may be a question as to his ability to draw a correct line between brown and black—there are all gradations—and between little and much woody texture—again, there are all gradations. I hesitate to

CLASSIFICATION OF COALS.

		Per Cent. of Pure Coal.
Graphite	Fixed carbon	over 99
Anthracite	Fixed carbon	over 93
Semi-anthracite	Fixed carbon	83 –93
Semi-bituminous	Fixed carbon	73 –83
Bituminous	Fixed carbon	47 –73
	Total carbon	80 –88
Sub-bituminous	Fixed carbon	47 –73
	Total carbon	73.6–80
Cannel	Fixed carbon	35 –47
	Total carbon	73.6–88
Lignite	Fixed carbon	30 –55
	Total carbon	65 –73.6
Peat and Turf	Fixed carbon	below 50
	Total carbon	below 65
Wood		

say that any one can do better than Mr. Collier, but think that *no line can be drawn.* Possibly some errors crept in, as I find often happens, and I regret to say, did happen in my original outline. The Cambria, Wyoming, coal and the Pennsylvania No. 3 were misplaced, but the data given them were such as to lead to the correct name.

With this explanation it seems safe to say that Mr. Collier is mistaken in thinking no method is worse than that proposed, based on chemical and physical tests, and using two factors. Exceptions are few, if the coal is a representative sample. It seems

best to present a revised outline, owing to the change in dropping "black lignite" as a type. Possibly some would prefer a use of the fuel ratio to the chosen one—fixed carbon in the pure coal. It can be calculated from this. If the fixed carbon is 90 per cent. of the pure coal the fuel ratio is $90/(100-90)=9$. Such values may be substituted in the outline. A knowledge as to any possible deterioration of the sample by weathering is to be taken for granted and the weathered coal may be placed in a different class from the fresh sample.

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October 26, 1909.

ORE-DEPOSITION AT ASPEN, COLORADO.

DISCUSSION OF PAPER BY J. E. SPURR.

Mr. Spurr stated in the introduction to his "Theory of Ore-Deposition"[1] that he was giving the reader but a preliminary outline to serve as a working hypothesis. His paper on "Ore Deposition at Aspen, Colorado"[2] concludes with an application of his theory to the local facts. Here too his arguments are brief and consider but one side of the question. The following questions by the present writer are therefore asked to draw out more detailed explanations of a few points not already clear.

Mr. Spurr notes that the three stages of ore deposition at Aspen are in reverse order to that stated in his general theory, and he states (p. 319) that "if the usual order results from a gradually lowering temperature, . . . then the reversed order must have resulted in this case from a gradually rising temperature, so that originally lower zones of ore deposition gradually rose till they overlapped and were superimposed on zones originally higher." The question now arises: if the earliest (barite) zone was followed by temperatures too high for its deposition, why was not much of the barite redissolved during deposition of the rich silver ores and, especially, of the galena-blende ores?

[1] ECON. GEOL., II., 8, p. 781, 1907.
[2] ECON. GEOL., IV., 4, pp. 318–320, 1909.

Why were not the rich silver ores in turn partially redissolved by the solution depositing galena-blende ores? The author states (p. 314) that he has seen specimens of crushed and brecciated polybasite, both with and without barite, cemented by galena; also that the occurrence of *angular* fragments of barite in the heavy breccia cemented by the galena-blende ores is abundant in the Smuggler Mine. No reference is made to evidence of solvent action on these fragments. Angular fragments of older rocks are of common occurrence in intrusive igneous rocks near contacts, but it is generally believed that such inclusions are not readily soluble in a magma that has cooled to its crystallization stage. The temperature, however, in such a case is gradually lowering. In the case at Aspen, conditions, according to the author, were just the reverse, and it seems to the present writer, without further knowledge of details, that metasomatic replacement of barite by the rich silver minerals, and of both barite and silver ore by the galena and blende should be expected. The author's statements (p. 313) of the relation between barite and rich silver ore suggest that resorption of barite is to be expected. The only mention by the author of replacement is on p. 314, where he states that the lead-zinc ores "have everywhere formed by filling the interstices of breccias and by rock-replacement to a less marked degree—especially of dolomite or limestone." No mention is made of replacement of ore or barite. In the ore-breccias, where the galena-blende solution was not in contact with either carbonate, why were not the fragments of barite and of silver ore corroded?

It is easy to conceive, as the author does, that by a rapid and violent intrusion the adjacent rocks are quickly raised to a maximum temperature and cool slowly in comparison; but it is not so easy to conceive of rocks being slowly heated to a maximum without being also gradually cooled, especially as the intrusive rock did not reach within 3,500 feet of the present surface (p. 309). The question now arises: why was not another stage of rich silver ore or barite deposited during, the cooling stage? The portion of the solution depositing the galena-blende must have carried barite, as no reason is given for a change in the composition of

the primary solution. Was this barite carried to points above the present erosion surface? If so, did the supply of ore-bearing solution give out while the temperature of the ore-zone was at its maximum? In other words was there no circulation of magmatic water after the intrusion, and consequently the rocks in the ore zone, had begun to cool? A more explicit statement of the conditions governing the "critical magmatic differentiation stage of ore deposition" (p. 319) will probably answer these questions; but it is not now clear to the present writer, how a differentiation which normally takes place during falling temperature can take place under a rising temperature.

The author states on page 311 that the Weber shales were very influential in producing precipitation. This influence, presumably and as held by Spurr in his monograph on Aspen, was that of a reducing agent. What are the relative solubliities of the vein minerals in question under such conditions? This question may require laboratory investigation for a final answer, but should be considered in a complete discussion of the question. Again, even if the shales were not influential in the formation of all the ore-bodies, were the relative percentages of barite, the rich silver minerals, and the galena-blende such that they crystallized in the order named? The experiments of Vogt in Norway and of the members of the geophysical laboratory at Washington show that, when crystallizing temperatures are reached, the mineral in excess of the ratio which gives equilibrium will crystallize first. May, then, the composition of the ore-bearing solution at Aspen have differed from those of solutions at other places where the paragenesis of the vein minerals is different? In other words, may the paragenesis of the ores at Aspen be attributed to the composition of the ore-bearing solution rather than to a slowly rising temperature?

G. F. LOUGHLIN.

REVIEWS

Graphite, Its Properties, Occurrence, Refining and Uses. By Fritz Cirkel, Dept. of Mines, Mines Branch, Ottawa, Canada, 1907. Pp. 307, 20 plates, and 9 maps.

In his letter of transmittal Dr. Cirkel states: "I have the honor to submit herewith my report on the graphite resources of the Dominion, together with a synopsis of what is generally known regarding graphite occurrences in foreign countries.

"I have added also a treatise on the subject of refining, and of the uses of the mineral, based on a personal inspection and examination of the more prominent graphite refineries, pencil and crucible factories in Canada, United States, Bavaria and Austria."

The book has much to recommend it in its completeness. A person consulting government reports treating of mineral substances, such as graphite, ordinarily wishes to know not only about the geological occurrence of the mineral, but also what it is good for; what it is worth; what are its characteristics; where it can be marketed; and how it is used. All of these questions are answered, though the geological discussion of certain localities is rather meager. The policy of the Canadian government in sending its investigators abroad to observe other occurrences and other modes of treatment is a good one. The investigator obtains a broader view of his subject, has more data from which to judge the deposits of his own country, and is correspondingly better fitted to inform his readers.

In Chapter I. Dr. Cirkel treats the history, use, and physical properties of graphite. The wide reading of the author is apparent from his copious and generally complete references.

Of the occurrence of graphite (page 18) Dr. Cirkel says:

"All over the United States and Canada, graphite occurrences can be counted by the hundreds, but so far a very small percentage warrant exploitation. Experience has demonstrated that actual mining should be undertaken with great precaution and with a broad knowledge of the characteristics of graphite ore and of the exigencies of the market. In some instances the deposits have contained a sufficient quantity of graphite, but it was so intimately mixed with other minerals, such as quartz and mica, that it was impossible to separate the graphite at a

sufficiently low cost to enter commercially into competition with graphite obtained from other deposits. The graphite from such deposits has been proved in the laboratory to be of a good quality; but commercial processes have not yet been devised for its profitable separation, especially from mica."

Besides this he might well have stated that even where processes for separation are successful, and the graphite deposit is apparently of sufficient richness, exploitation may not pay, as the graphite industry at present depends as much on commercial organization and distribution as upon the working of the deposit itself. Many firms have failed in the United States, not because their deposits are poor, or their separation processes faulty, but because they could not market their graphite profitably after it was prepared.

Graphite with iron ores is noted in Canada, Scandinavia, New Jersey, and New York, and mention is made of its occurrence in meteorites, whence come fine graphite crystals. Graphite is generally found in the oldest crystalline rocks, which are without other evidence of organic matter. However, it is also found with coal in younger rocks, as in Rhode Island, Massachusetts, New Brunswick, and near Paltenberg in the northern Alps. In the latter place it is with difficulty separable from anthracite. The largest and most valuable graphite deposits appear to be in pre-Cambrian crystalline rocks. The Cambrian deposits are in gneiss and crystalline limestone of Laurentian age in the upper Grenville series. The Ceylon deposits are in the Laurentian granite, and the Siberian deposits at Batuga, Province of Irkutsk, are between syenite and granite.

Dr. Cirkel classes the deposits genetically as: (1) vein-like occurrences; (2) bed-like occurrences; and (3) disseminations through country rock. This classification being founded upon the form of the deposit, can not properly be called genetic.

In the first class are deposits north of Ottawa, near Grenville, in Ceylon, at Borrowdale, and at Batuga. These veins are in most places filled with graphite in fibrous or rod-like aggregation.

The second class of deposits (bed-like) conform in general with the bedding of the country rocks and are mostly lenticular. The deposit near Kaiserberg, Styria, where coal has been changed to graphite, is given as an example, but the metamorphosing agent is not mentioned.

In the third class, disseminated deposits, are placed those deposits in which the graphite is distributed through the rock in mere flakes. Graphitic veins sometimes traverse beds containing disseminated graphite, and the author supposes that the disseminated particles have come from them. Dikes cut the beds in many places, and the author infers with beneficial effects. It appears equally reasonable to suppose

that organic matter in the rocks has been altered to graphite, and that both flakes and veins were formed during the process, or the veins may have been formed through later segregation. The reviewer has seen graphite veins in the Black Hills of South Dakota, which appear to have been formed by the segregation of graphite from graphitic schists, but the veins are not of sufficient purity to be worked.

The graphite deposits of Canada are described in detail. They occur in the province of Quebec, New Brunswick, Nova Scotia, British Columbia, and near Hudson Strait. Those worked are in Quebec and New Brunswick. Most of the exploited deposits are of the disseminated type and are either in limestone or in gneiss. Veins of very pure graphite occur but they are of uncertain extent and the disseminated deposits have proved more valuable.

After the Canadian deposits, the principal occurrences in other countries of the world are treated.

A chapter is devoted to the origin of graphite, but Dr. Cirkel contents himself mostly with a compilation of the views of others. He apparently believes the graphite in granite and similar rocks to be of igneous origin, and (page 95) the disseminated flakes in limestone to be derived from graphite originally present in the rock as organic matter. However, when it comes to veins of graphite traversing this same limestone, he attributes their origin to some deep source. Bedded deposits are in places clearly altered coal beds. Probably the best examples now known of such alteration are the beds in central Sonora, Mexico, but of these there was no published description at the time Dr. Cirkel wrote his monograph.

The composition of graphitic ores and the commercial properties of graphite are treated at length. The disseminated ores utilized in Canada carry from 7 to 30 per cent. graphite. Ordinarily, disseminated ores cannot be worked profitably where the graphite falls below 5 per cent. American operators have told the reviewer that this figure is too low, and that ores to be profitable should carry a higher content unless the miner himself expects to manufacture the graphite into marketable products.

The three principal uses of graphite are stated to be for (1) crucibles, (2) pencils and (3) antifriction compounds and paints. Putting the last two together is rather questionable. It is the common practice of graphite manufacturing companies to put their poorest product into paint and many graphites are put into paint which would have no other possible use, while for lubricants only the very finest grade can be used.

C. Bishop is quoted to the effect that in the manufacture of crucibles it is not so much the quantity of impurities in the graphite that affect its value, as the liability of some of these to flux with the clay used.

For the manufacture of pencils Dr. Cirkel states that only homogeneous, fine, scaly, lammelar varieties can be used. It is probable that such varieties have been used because the pencil companies could get nothing better. At present a large part of the best pencils made in America and Europe are manufactured from an amorphous graphite from Sonora, Mexico. One firm, whose pencils bear the inscription "Made from British Graphite," is said to use the Sonora material altogether in their best pencils. Canadian graphite, treated with hydrochloric acid, is said to also make good pencils.

Tests are quoted to show that graphite from the Black Donald Mine (Canada) when properly selected, is as suitable for crucible-making as the best Ceylon graphite. A number of tests by Dr. C. Hoffman are given which show that Canadian graphite of selected sorts is almost as incombustible as that from Ceylon. One lot of thirty tons, made into crucibles, both by American and European firms, gave excellent results.

Graphite crucibles are sometimes adulterated with coal dust, and an acetone test is given for the detection of this fraud.

Many methods for the analysis of graphite are presented in detail. All of those which aim at great exactness are troublesome, though approximate analyses can be made with comparative ease.

Concerning the production of graphite in Canada, it is stated that the highest value reached was in 1901, when 2,210 short tons, valued at $38,780, were produced. In 1904 only 450 tons, valued at $11,760, were mined.

In 1902, the last year for which exports of graphite from Ceylon were given, the United States was the largest importer, this country taking 12,611 long tons as against 6,773 shipped to England. Ceylon graphite is used almost wholly for making crucibles.

In production the United States was third, with Ceylon first and Austria second .

The following estimate given of uses is interesting:

Manufactures.	Per Cent.
Refractory articles, as crucibles, stoppers, nozzles, etc.....	35
Stove polish	30
Lubricating graphite	10
Foundry facings	8
Graphite greases	6
Pencil lead	4
Graphite packing	3
Graphite paint	3
Electrotyping and miscellaneous	1
	100

Chapter 8 is devoted to methods and machinery for handling the ore, including hand-sorting, drying, rock breakers, rolls, ball mills, emery and burr stones, and tube mills. The latter three are used for polishing and grinding flakes. Separating and sizing machinery is discussed and described at length.

The author states that graphite can be separated electrolytically from its gangue. In a discussion of wet and dry methods he is inclined to believe that wet methods are best for separating the gangue, especially if clayey, from the graphite, though air methods are easier to handle in cold climates. Oil concentrations are also discussed. In the majority of cases mills lose from 15 to 30 per cent. of the graphite mined, and in others the loss runs up to 50 per cent. The treatment of graphite is one of the most difficult problems in ore concentration.

To get rid of the ash; that is, those impurities that cannot be eliminated mechanically from graphite, such as the silica skeleton about which graphite flakes are often formed, chemical methods are necessary. A number of chemical purification schemes are given, most of which depend upon roasting to get rid of sulphur, an acid solvent for iron, and a solvent for the silica. It is stated on the authority of another, that under such treatment graphite may be made eighteen times as good a conductor of electricity as crude graphite.

The uses of graphite are fully described. Dr. Cirkel quotes from an Austrian paper of 1878 that the Joseph Dixon Crucible Company used Ticonderoga graphite in making crucibles. This may have been true at that time, but the company now uses Ceylon graphite almost wholly, although it seems probable that a certain percentage of their own flake graphite is used in some qualities. The columnar or granular structure of the Ceylon graphite makes it much more suitable for crucible making than the flakey Ticonderoga graphite.

The great growth of the steel trade has increased the demand for graphite of a quality sufficiently good for making crucibles, so that the output of Ceylon in 1902 was six times its output in 1868, although these mines have been worked to a greater or less extent for many years. It is to be noted that American crucibles are sold in Europe as well as America. The manufacture of crucibles, including machinery for the purpose, and the handling of crucibles after manufacture, is treated at length. Many details of the manufacture of crucibles for withstanding different temperatures are given. Graphite begins to oxidize at 600° C., so that efforts have been made to prevent this oxidation by some sort of a glaze. It will be a surprise to most readers to see the statement that it is more difficult to make crucibles to stand moderate heats than to stand intense heats. This is owing to the different sorts of clay which must be used in the mixture.

Besides the making of crucibles, the manufacture of phosphorizers for introducing phosphorus into molten metals is described. Graphite brick are mentioned, and the making and use of kryptol, a compound of graphite, carborundum, and clay, for electric resistances for heating, is described.

The history and manufacture of lead pencils is treated at length. It was not until 1795 that the process of mixing clay with graphite for pencils was invented, when Conde of Paris, and Hartmuth of Austria developed the method simultaneously. Even with this improvement it was not found possible to form perfectly homogeneous grades in hard pencils. This is now done by dipping the dried pencils in some salt, *e. g.*, sulphate of soda, after which the pencil is again dried and burned. American ingenuity is in evidence in cutting pencil wood, and such operations are wholly effected by machinery. In the United States, 300 tons, or 20,090 cubic feet of wood per day is used for making pencils. This amounts to 100,000 tons, or 7,300,000 cubic feet per year. Lately the Forest Service has taken up re-forestation of cedar lands depleted by this manufacture.

The use of graphite as a lubricant is growing greatly, and Dr. Cirkel notes that 125 patents have been issued for lubricants of which graphite is a component part.

The author very strongly commends flake graphite for a lubricant, but this is open for discussion. It is certainly true that in many places the best grade of amorphous graphite is satisfactorily used as a lubricant. In paints the use of flake graphite is championed as against amorphous graphite, and yet he countenances the use of silica in the same paint as a filler. The use of graphite in paint would seem to be founded upon the formation of an elastic, inert skin, or coating, upon the substance to protect it from water, fumes, insects, etc. Graphite seems to fulfill this condition well, the oil acting as a cement between the particles. Graphite should also act as a filler as well. Silica offers sharp points, through which the oil is most easily attacked.

The use of graphite in electrotyping, as polish for stoves and gunpowder, and for minor uses, is mentioned. A use to which little attention has hitherto been called is as scale preventative in steam boilers. It is claimed that graphite not only prevents the formation of scale, but softens the scale already formed.

The excellent report closes with a bibliography of 40 titles.

FRANK L. HESS.

History of the Clay-working Industry in the United States. By Heinrich Ries, Ph.D. and Henry Leighton, A.B. 8vo, pp. ix + 279. John Wiley & Sons, New York, 1909.

This work is distinctly different from any other relating to the clay industry. It cannot but be of value and interest not only to those engaged in any branch of the ceramic industry, but to students of the history, especially the early history, of the development of manufactures in this country.

The volume is the result of work done for the Department of Economics and Sociology of the Carnegie Institution of Washington, and it could not have been intrusted to better hands. Few of us will realize the amount of work, and in many cases drudgery, required to collect the data for this volume. The bibliography included in the work indicates in some degree the sources of information, but an examination of the text shows these sources to have been greatly augmented and corrected by a vast amount of inquiry in person and by letter. No one has personally covered so large a portion of the country in the study of its clay resources as Dr. Ries, whose reports on the clays of the United States and of the several states where he has worked, have made but slight references to the history of the industry, and this work rounds out to a large degree his previous reports. The work is well written and but few mistakes are to be noted, and where noted they are mistakes of the authorities followed, and not of the authors.

The work should have its place in the library of every clay worker and economic geologist.

Richard R. Hice.

A Handbook for Field Geologists. By C. W. Hayes, Ph.D., Chief Geologist, U. S. Geological Survey. 2d Ed. New York, John Wiley & Sons, 1909.

The second edition of this excellent little book attains its excellence chiefly in the fact that it still remains what the first edition purported to be, namely, a Handbook for Field Geologists in the United States Geological Survey. The attempt of the author to give the second edition a broader scope and make it a handbook for field geologists in general has only been partially successful. Throughout the book it is apparent not only from the context, but also by direct statement that the instructions as to how to conduct geological work have reference to the requirements of the survey as a complex organization rather than to the simpler needs of geological science. Indeed, this is so obvious in the first part of the book that it would be quite unfair to criticize it from any other point of view than that it is chiefly a set of official instructions for the guidance of the officers of the survey. The author divides

his book into two parts entitled (I.) General Instructions and (II.) Instructions for Special Investigations; but under the second part are included certain schedules which might with advantage be separated as Part III., since they are really the distinctive feature of the book and the only part to which repeated reference is likely to be made by those following the instructions.

In Part I. the criticism which naturally occurs to the reviewer is one which the author has himself anticipated, but not disposed of, namely, that it is strange that geologists should need instruction in such elementary matters. A geologist would naturally be interested in glancing over these pages as he would those of any paper from so eminent a pen, but unless he be an officer of the survey having administrative rules to obey regarding the conduct of parties, relations to the public, requisitions, topographic errors, land classification surveys, labels, samples, chemical analyses, nomenclature, permission to publish, etc., etc., he would doubtless, having satisfied himself that there was nothing new in it of especial interest, put it carefully away on a shelf. So that while Part I. may be a handbook for officers of the survey, and the author from his official position is the best judge of this, it certainly would not be regarded by ordinary geologists as a book to which frequent reference should be made in the pursuit of their usual studies. Of course under the title of the first edition the criticism falls to the ground since it is doubtless very desirable in a large organization like the survey that methods of work and particularly methods of recording observations be to some extent standardized. Even as a compendium of common practice and methods to which a young student might be referred it is not altogether satisfactory, since the practice and methods of geologists are more comprehensive than those of the U. S. Geological Survey. For example, under the head of horizontal measurements the use of the micrometer telescope is not mentioned, although it has been extensively used in geological surveys in North America for the last 60 years and is a most useful instrument for rapid work in a new country, particularly for streams and lake shores. In the same connection one of the most common of all methods of measuring distances for purposes of location in geological work is compass triangulation. The method should at least be mentioned in the list on page 21. Again in the matter of vertical measurements no mention is made of the use of the mercurial barometer. Under many conditions of field work a pair of portable mercurial barometers is by far the most satisfactory way of getting differential elevations, being susceptible of rapid use and under the method of simultaneous readings, extremely accurate. Much might be said in favor of even a single mercurial barometer. The fact that the U. S. Geological Survey does not use the micrometer telescope

and the mercurial barometer is a poor reason for omitting reference to these instruments and their use in a compendium of methods, but is of course ample justification if the book be intended, as it originally was, for officers of the survey. In the matter of instruments also the Attwood compass-clinometer-handlevel should be at least mentioned, if only for the benefit of the young student; and the defect in the Brunton should be pointed out, that in mine work there are many situations in which it cannot be used as a clinometer, owing to the difficulty of seeing the level bubble, whereas in the same situations, and in all others, the Attwood may be used with facility.

The subject of geological nomenclature is a painful one, but of course a handbook invariably relieves our pain—by making us laugh. Mr. Hayes's handbook is no exception to this invariable rule. He gives us two paragraphs of platitudes and three in quotation marks from the rules of the survey. The humor is irresistible. How delightfully easy it will now be for the weary field geologist after his summer's labors on say several thousand feet of the Cretaceous to reach out for his handbook and ascertain beyond peradventure whether they constitute a formation, or a group, or a series, or a system!

Part II. of the handbook up to the schedules is a very readable, even if quite academic, discussion of the scope, purpose and method in outline of investigations pertaining to geomorphology, petrology, tectonics, glaciology and economic deposits. It is interesting because it is somewhat more modern than any of the texts at present available for young students and also because of the point of view from which it is written. It is evident from a perusal of it that the author could, if he would, write a very admirable book for students.

But while this part of the book has undoubted merit as a fingerpost to beginners in geoloical work it suffers from condensation and omissions. At the same time it is unnecessarily elaborate as an introduction to the schedules recommended for use to trained and seasoned geologists. Men competent to use the schedules have no need of the introduction, and students who would like to become proficient in their use would never acquire proficiency by reading it. The only useful purpose which the text can serve being as an aid to beginners it is woefully lacking for this purpose in those concrete illustrations which are universally recognized as necessary in elementary texts. Generalizations such as abound in these pages would be delightful and stimulating to the student if properly illuminated by reference to a few of the representative studies upon which they are based.

Indeed, the absence of illustration and examples renders the meaning in some instances obscure. Thus in the general characteristics of a peneplain "absence of undrained areas" is listed. The only undis-

sected peneplain which the reviewer has had the good fortune to behold is notably characterized by extensive sheets of stagnant water. The presence, therefore, and not the absence, of undrained areas may be listed among the features of peneplains. Again "the lack of interruption of peneplain surface on rocks of very different resistance" is mentioned as a characteristic of peneplains immediately after monadnocks, which are exemplifications of interruption of peneplain surface on rocks of different resistance. Peneplains usually show in their surface relief the effects of differential resistance to erosion, except in those portions which are genetically wave cut or steam cut terraces.

Under the head of igneous rocks the first instruction to the field geologists is to "observe the mineral composition and texture carefully"; but there is no intimation of the very severe limitations to such a laudable effort. Why exhort the student to do in general what is only possible in a small percentage of the cases with which he has to deal? Under sedimentary rocks non-clastic siliceous deposits are not mentioned and crossbedding is referred to wave action! In the section on structure there is nothing which would be of practical aid to any one undertaking the study of a region of complicated faulting. The specification of the criteria whereby earlier Alpine glaciation may be recognized is deficient in not referring to the most commonly available criteria.

In the discussion of ore deposits no reference is made to the important rôle played by gouges developed on fault fissures in controlling the distribution of ore deposition, nor is any allusion made to the influence of climate on the nature of deposits. In the study of placer deposits "the distribution of the mineralization in the bed rock from which the placer deposits have been derived" is emphasized, although it is difficult to see how this information, even if available, as it rarely is, would effect practically the study of the placer deposits at say Oreville, Calif. A more important piece of information for practical purposes would be the size of the boulders, many rich placers being unworkable by reason of the huge boulders which abound in them.

These are some defects that have been noted in an interested reading of the instructions for special investigations; but perhaps the most serious defect of all is the failure to emphasize, or even to recognize as a special investigation, the matter of correlation. This is a very special problem in nearly all geological work, and particularly for that class of work which has to do with areal mapping. Insufficient and ineffective effort at correlation is the chief weakness in our cartographic geology in the United States at the present time, and some instruction tending to improve this condition of affairs would have been useful.

The schedules which follow the instructions for special investiga-

tions are a series of commendable schemes for the systematization of the observational record in various branches of geology. They will be found serviceable not only to the beginner in geological work, but also to the experienced geologist, although the latter will doubtless modify the scheme in any given case to suit himself. The schedules afford suggestions not only for the compilation of field notes preparatory to office study and final discussion, but also for the arrangement of material in that discussion. The only serious criticism of the schedules that their inspection suggests, is that in most cases they are so comprehensive that they far transcend the domain of geology. Thus in Schedule 5, dealing with precious and semi-precious metalliferous ores, categories 4 to 9 inclusive or two-thirds of the schedule have to do with the functions of the mining engineer and not the geologist. The same is true of Schedule 6, and is true to nearly the same extent of Schedules 7, 8, 9, 10, 11, 12, 13 and 14. In other words the greater part of the schedules, though purporting to be for the use of field geologists, pertains to matters with which the geologist as such is not directly concerned.

ANDREW C. LAWSON.

Elements of Optical Mineralogy, an Introduction to Microscopic Petrography. By N. H. WINCHELL, A.M., AND ALEXANDER N. WINCHELL, Doct. Univ., Paris. Octavo, 502 pages, 350 figures in the text, and 4 plates. New York, D. Van Nostrand Company, 1909, $3.50.

The announced purpose of this book is to furnish "a clear and concise account of the principles, methods and data" relating to the microscopic investigation of minerals. The object was undoubtedly worth while, for prior to the appearance of this volume there was, in English, only one comprehensive modern text-book on the subject;[1] a book which, though of much merit, might be improved upon, especially for certain kinds of students. But the authors undertook an exacting task. The writing of a concise manual, even more than that of a voluminous treatise, demands the exercise of keen judgment regarding what is essential, a feeling for coherent and orderly arrangement, and a faculty for effective and lucid exposition. The present volume must be appraised, in the main, according to the degree in which it proves its authors possessed of these qualifications; and it may as well be said at once that it does not do this altogether successfully. Its defects are partly counterbalanced, however, by the presence of some features not found in other text-books.

The volume comprises three parts. Part I., of 100 pages, is devoted to principles and methods; Part II., of 312 pages, to descriptions of

[1] Iddings, J. P., "Rock Minerals," New York, 1906.

minerals; Part III., of 62 pages, to tables for their determination. There are appendices on the optical study of opaque minerals and on microchemical methods.

Part I. comprises three chapters, the first entitled "Certain Phenomena of Light;" the second "Elements of Mineralogy;" the third "Application of Polarized Light to Crystalline Substances."

The general order of treatment indicated by these chapter-headings is open to the criticism that the discussion of light phenomena is interrupted by a chapter on matters largely unrelated to it. In Chapter III., moreover, where the polarization phenomena of the respective crystal systems are considered in turn, the treatment of double refraction falls almost wholly under "Hexagonal Minerals," a caption which covers not only much pertaining to doubly refracting minerals in general, but some details, regarding the microscope and its accessories, that are even more out of place. The lack of systematic arrangement thus exemplified—exemplified also by some needless repetitions and by the desultory manner in which chromatic interference phenomena are treated (pages 46, 49, 51, *et seq.*) is a real detriment to the usefulness of the first part of the book. Its effect is aggravated by lack of judgment in the use of headings, which form the very skeleton of a well constructed work of reference.

The choice of subject-matter is marked both by unwise inclusion and by unfortunate omissions. Chapter II., entitled "Elements of Mineralogy," but really devoted almost exclusively to mathematical crystallography, contains little that the student might not find in one of several elementary text-books. On the other hand, the directions for determining specific gravity (page 38) would be more useful if more were said of the manipulations involved. One would welcome also some general discussion of the relations between crystallographic and optical symmetry, and a compact summary of the means of determining the crystal system of a mineral. Elsewhere in the book important matters are neglected. The effect of inclined illumination (page 12) may be the reverse of that described. The directions for measuring the thickness of a section (page 62) omit the essential fact that the apparent thickness is to be multiplied by a fraction whose numerator and denominator are respectively the refractive indices of the substance measured and of the fluid in which the objective is immersed. It would have been well to describe, in addition to Michel Lévy's comparator, some of the compensating instruments for measuring double refraction, since these are more accurate for colored or weakly birefringent minerals.

The style of the work has the merit of being generally simple. It is not, however, especially precise, and at some critical points the language is not explicit enough. For example, the definition of the stereographic

projection (page 25) will hardly convey a meaning to the average student, and the sentence at the top of page 71 on "axes of ether vibration" (a term less suggestive than "principal axes of elasticity") is obscure if not incorrect. The word "parameter" does not appear to be defined; the definition of "sign of elongation" appears only as an addendum, and the useful term "crystal habit" is not introduced.

A more radical fault apparently arises from failure to realize the obligation involved in undertaking to present *principles* as well as the methods and data which are all that mere determinative manuals, as distinguished from text-books, can be expected to give. Not only in the passages on interference colors, but in those relating to the simplest phenomena of double refraction, and even in that on single refraction, assertion too often takes the place of proof. This is partly because the authors have almost entirely neglected the concept of wave-surfaces. Only through the use of this concept do the fundamental laws of refraction become amenable to mathematical discussion. The concept of rays, in terms of which light phenomena are almost exclusively discussed in this volume, is, while indispensable for certain purposes, distinctly more abstract than that of wave-surfaces and can not take its place in the exposition of basal principles.

Praise is due to figures 57 to 58 E, which represent in clinographic projection the behavior of light rays passing through crystals, and to the "laboratory illustrations," which might well have been used more freely and systematically.

Part II. is modeled after the second part of Michel Lévy and Lacroix's "Minéraux des roches." The arrangement is alphabetical. Minerals of a group are treated together under the group name, but since their specific names are also given in their alphabetical place with a cross reference to the group, the description of any given mineral is readily found. The aim has evidently been to make the descriptions systematic and as concise as possible. Occurrence is treated in very brief and general terms, with few references to localities excepting in the case of rare minerals, and few original descriptions are cited. Diagnostic features are pointed out with some fullness.

The adoption of a somewhat rigid scheme has gone far to save this part of the book from the defects of arrangement apparent in Part I. The descriptions are generally clear and adequate.

The section on the feldspars, however, is disappointing. Eleven years ago the senior author published[1] an account of the methods of feldspar determination, drawn chiefly from the classic writings of Michel Lévy and Fouqué. This summary was useful and timely when

[1] Winchell, N. H., "The Determination of the Feldspars," *Amer. Geologist*, Vol. 21, 1898, pp. 12–49.

it appeared, but it is strange to find it embodied in the present volume with almost no substantial change except the addition of a description of the barium feldspars. For the plagioclases the old data of the French petrographers are uncritically retained, to the neglect of the more accurate determinations made in the last decade by Becke and other Germans. The great usefulness of the section normal to (001) and (010) is not pointed out, and the statistical method is given undue prominence. It is astonishing that there is no mention of the method depending on equal zonal illumination, nor of the more accurate one, due likewise to Michel Lévy, depending on the concurrent extinction angles of Carlsbad twins.

The general arrangement of this account of the feldspars leaves much to be desired; witness the placing of the section on classification midway (page 212) instead of at the very beginning, and the inclusion of paragraphs on isomorphism and on nomenclature, under the heading "Sections parallel to the brachypinacoid" (pages 223–227).

The interesting tabulation (page 227) of nine schemes of nomenclature (to which two or three might be added) brings into relief the fact that species names ought not be used in quantitative statements without giving the percentage of anorthite. Failure to do this greatly diminishes the value of the table on page 212. Tables, at best, are less useful than diagrams representing extinction angles by curves, and several such ought to be added to the book.

Figures 116–121, 123 and 124, which exhibit the optic axes and axes of elasticity in clinographic projection, will greatly help the student to imagine the approximate optical orientation of the feldspars.

Part III. is perhaps most successfully accomplished. In the tables there given the minerals are classified first as opaque, isotropic, uniaxial or biaxial; then, successively, according to: refringence, birefringence, optical sign, crystal system, and sign of elongation. These tables appear to be practical and convenient.

The microchemical methods briefly treated in the appendix are the well known ones of Boricky and Behrens. Of more interest is the translation of an article by Königsberger, which gives a novel and brilliant method of determining the orientation and crystallographic symmetry of opaque minerals by means of light reflected from their highly polished surfaces. The translation is useful, but one would like to find some account of the principles underlying the method, and also some description of the other methods of metallography.

There is a reproduction of Michel Lévy's rainbow plate for the measure of double refraction, and a useful table in which the refringence and birefringence of all transparent minerals are given with their range of variation.

The quality of the paper used in the book, and that of many of the illustrations, unfortunately falls as far below modern American standards as the latter fall below the European. Only durable white paper is fit for a book to be used for reference by readers to whom unnecessary strain on the eyes is a hardship; and a diagram's clearness or illegibility may determine whether it will be comprehended by an immature student.

The most distinctive and valuable feature of the book has been reserved for final mention. It is the inclusion of *all* minerals whose optical properties are sufficiently known to be used in diagnosis. A large proportion of the species thus added to the "rock-forming minerals" commonly treated in petrographic manuals are of economic interest; and the practical geologist who uses the microscope will find compactly presented in Parts II. and III. many useful data which have hitherto been widely scattered and difficult to find.

Perhaps the authors, although they do not say so, considered especially the needs of those students—probably forming the majority of American university classes in petrography,—who intend to apply their knowledge to economic problems. It is chiefly because there is a place for a book designed to meet such needs, and because this book might through revision be made to do so, that the present criticism has been made so detailed. As it stands the volume can not be highly recommended as a text-book; but to a great number of economic geologists it should prove highly useful, not to say indispensable.

F. C. CALKINS.

SCIENTIFIC NOTES AND NEWS[1]

IN THE REVIEW of "The Geology and Gold Fields of British Guiana" in number 5 of the current volume of this journal attention was called to an ambiguity of statement that left the reader in doubt as to who is responsible for the many excellent chemical analyses there discussed. It was also pointed out that the value of the evidence for the presence of gold in the various rocks studied is impaired by failure to state clearly whether analyses and assays were made on identical samples. Mr. J. B. Harrison, Government Geologist of British Guiana, has written that he is personally responsible for all analyses and assays given in the book and that out of 58 analyses published 52 were made on material taken from the same sample assayed. The editor is pleased to record this supplementary information.

ROBERT HAWXHURST, JR., has resigned the management of the Ponderosa Mining Co. of Collahuasi, Chile, and returned to London.

IT IS THE AIM of the Geological Department of Ohio State University to make its instruction as practical as possible. Consequently, during the last term numerous field trips for the advanced students have been made. Professor Bownocker has made various trips for the purpose of studying glacial geology, some of the longer of which have been to Bremen and Lancaster and to Fort Ancient. In statigraphical geology Professor Prosser has conducted a trip every Saturday. The Silurian formations were studied at Yellow Springs, Clifton Gorge, Cedarville and the Darby creeks near Georgesville; the Devonian on the Scioto River near Columbus; the Mississippian at Lithopolis, Black Lick, Gahanna and Newark east of Columbus; and

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

the Pennsylvanian on Bald Hill near Newark and at Zanesville. As a result of these trips the students have studied in the field each formation found in the state from the Richmond in the Cincinnatian series of the Ordovician system to the Middle Kittanning or No. 6 Coal of Ohio in the Allegheny formation of the Pennsylvanian series of the Carboniferous system, making a total of eighteen formations exclusive of the glacial. During this term emphasis has been put upon the structure and the characters for recognizing and limiting these formations; but next fall these students will give more attention to the fossils of the various formations, when several longer field trips will be made.

THE RHODE ISLAND LEGISLATURE has appropriated $2,500 annually for three years for a survey of the natural resources of the state. The work was placed under the general charge of the Bureau of Industrial Statistics, Col. Geo. H. Webb, commissioner, who has appointed Professor Charles W. Brown, head of the department of geology at Brown University, to take immediate direction of the survey. Mr. Nelson C. Dale, A.M., and I. R. Sheldon, '10, have been appointed field assistants.

MR. J. A. TAFF has resigned from the U. S. Geological Survey to take a position as geologist with the Southern Pacific R. R. Co. Mr. Taff will have his office in the Flood Building, San Francisco.

MR. J. M. BOUTWELL is in Washington finishing his Park City report for the U. S. Geological Survey.

AT THE MEETING of the American Institute of Mining Engineers held in Spokane, Washington, during the latter part of September and the early part of October a large number of papers were presented, most of them read by title only. Those which are of chief interest to students of Economic Geology are as follows:

"The Formation and Enrichment of Ore-bearing Veins," by George J. Bancroft, of Denver, Colorado.

"Need of Instrumental Surveying in Practical Geology," by Benjamin Smith Lyman, Philadelphia, Pa.

"An Adjustable Pyrometer Stand," by L. W. Bahney, Palo Alto, California.

"Dredging for Gold in French Guiana," by Albert F. J. Bordeaux, Thonon les Bains, France.

"Barite Industry of the United States," by A. A. Steel, Fayetteville, Arkansas.

"Federal Coal Mines in the Philippines," by Oscar H. Reinholt, Passadena, California.

"Discussion" of paper by Charles R. Keyes, "Genesis of the Lake Valley Silver Deposit," by William M. Courtis, Detroit, Mich.

"Discussion" of the paper of Charles R. Keyes, "Ozark Lead and Zinc Deposits; their Genesis, localization and migration," by E. R. Buckley, Flat River, Mo.

"Discussion" of paper by D. F. Hewett, "Vanadium in Peru," by James F. Kemp, New York.

"The Conservation of our Coal Supplies," by Edward W. Parker, Washington, D. C.

"Borax Deposits in the United States," by Charles R. Keyes, Des Moines, Iowa.

AT A MEETING of the New York Academy of Sciences held November 1, 1909, at the American Museum of Natural History in New York, two papers of considerable interest to economic geologists were read. They were as follows: "Galena, Barite and Fluorspar Veins of Western Kentucky," by Mr. F. Julius Fohs, of the Kentucky Geological Survey, and "Application of the Law of Mass-action to Phenomena of Resorption in Igneous Rocks," by C. N. Fenner.

MR. EDWIN HIGGINS has resigned his position of assistant editor of the *Engineering and Mining Journal.*

MR. T. EDMUND WOODMAN, formerly professor of geology in Dalhousie University, Halifax, Nova Scotia, is now professor of geology in New York University. His address is University Heights, New York City.

ARTHUR K. ADAMS, for the past two years head of the Department of Mining Geology at the New Mexico School of Mines, has recently resigned in order to accept the appointment of mineral inspector in the General Land Office, with headquarters at Huron, S. D. He will be succeeded at Socorro, N. Mex., by Frederick Paul, Ph.D. (Freiberg).

THE WEST VIRGINIA Geological Survey has just issued an important volume pertaining to the mineral resources of the state. It is numbered Volume IV. of the general series, and is described as follows:

Volume IV., "Iron Ores, Building Stones and Other Minerals," 603 pages, cloth, just issued from the press at this date (September 25, 1909). This volume gives descriptions and analyses of all the principal iron ore deposits of the state, together with a history of the old charcoal furnace industry. The main building stones of the state are also described and elaborate tests of their strength and crushing limit made by the War Department at the Watertown Arsenal, and also by the U. S. G. Survey Testing Laboratory at St. Louis, together with chemical analyses, petrographic determinations, etc. The glass sands are also described and analyses given. The salt industry and the different brines of the state are also fully described, and chemical analyses published. The report is illustrated with 24 page plates, and 16 figures and maps and in the text, showing location of iron ores, geological structures, illustrations of blast furnaces, etc. Price, postage paid by the survey, $2.00 when ordered separately, or $2.25 with coal, oil, gas and limestone map. For other combinations at reduced rates, including all the remaining publications of the survey, write to the West Virginia Geological Survey, Morgantown, W. Va.

TWO YEARS AGO Professor Charles S. Prosser visited most of the large American universities and spent some time at each in studying equipment and methods of instruction. This year he has given a course of lectures to the advanced students in geology describing the opportunities for graduate study in geology at

some of the leading American universities. The institutions to which the greatest attention has been given are Johns Hopkins, Princeton, Columbia, Yale, Harvard, Cornell and Chicago.

MR. T. MORGAN CLEMENTS has opened offices at 1707 Broadway, N. Y.